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DNA 4142T

# DYNAMICAL SOLUTION OF THE SGEMP ELECTRON BOUNDARY LAYER FOR LINEARLY RISING AND CONSTANT X-RAY TIME HISTORIES

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Mission Research Corporation
735 State Street
Santa Barbara, California 93101

December 1976

Topical Report for Period October 1976—December 1976



CONTRACT No. DNA 001-77-C-0009

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Director
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18 DNA, SBIE 19 4142T, AD-E300 082

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SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>DNA 4142T | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER<br>9 |
| 4. TITLE (*and Subtitle*)<br>6 DYNAMICAL SOLUTION OF THE SGEMP ELECTRON BOUNDARY LAYER FOR LINEARLY RISING AND CONSTANT X-RAY TIME HISTORIES. | | 5. TYPE OF REPORT & PERIOD COVERED<br>Topical Rep[redacted]t. [redacted]<br>Oct[redacted]-Dec[redacted]76 |
| | | 6. PERFORMING ORG. REPORT NUMBER<br>14 MRC-R-300 |
| 7. AUTHOR(*s*)<br>10 N. J./Carron | | 8. CONTRACT OR GRANT NUMBER(*s*)<br>15 DNA 001-77-C-0009 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Mission Research Corporation<br>735 State Street<br>Santa Barbara, California 93101 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>16 Subtask R99QAXEE502-10<br>17 E502 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Director<br>Defense Nuclear Agency<br>Washington, D.C. 20305 | | 12. REPORT DATE<br>11 Dec[redacted]76 |
| | | 13. NUMBER OF PAGES<br>56 12 52p. |
| 14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*) | | 15. SECURITY CLASS (*of this report*)<br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B323077464 R99QAXEE50210 H2590D.

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

SGEMP Boundary Layer
Electron Boundary Layer
Photoelectron Emission
X-ray Photoemission

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)


The time dependent solution is presented for the dynamical behavior of the one dimensional electron boundary layer formed when X-rays knock photoelectrons out of a material surface. The X-ray flux is taken to be either linearly rising in time or constant in time. Two electron energy spectra are considered—exponential and linear-times-exponential. The electrons are assumed to have a cos $\theta$ emission distribution.

The electric field, potential, charge density, and current density are given


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20. ABSTRACT (Continued)

as functions of distance from the surface and time. The layer's dipole moment per unit area and its first and second time derivatives are given as a function of time.

The current density may be useful as a prescribed current for Maxwell solving codes. The dipole moment and its derivatives may be useful for estimating quasi-static and radiated dipole fields.

## CONTENTS

## SECTION 1
## INTRODUCTION

This report presents scaled numerical solutions for the one dimensional time-dependent SGEMP electron emission boundary layer problem in the two cases in which the incident X-ray flux is either linearly rising in time (a linear ramp) or is constant in time starting at $t=0$ (a step function). Two electron energy spectra are considered in each case, an exponential spectrum, and a linear-times-exponential spectrum. The electrons are assumed to be emitted with a $\cos\theta$ angular distribution. The scaled solutions given here provide the solutions to real problems with these energy spectra for arbitrary X-ray flux rise rates (for the linear ramp) or arbitrary fluxes (for the step function).

Most X-ray pulses start off rising linearly in time. In many cases, especially at high fluences or long rise times, much of the interesting boundary layer dynamics is taking place while the pulse is still linearly rising. Since a single solution suffices for all rise rates during this portion of the pulse, it is worthwhile to present this solution.

In addition, if the pulse rise time is very short compared to an electron turnaround time and compared to the subsequent time over which the remainder of the pulse varies significantly, then the boundary layer will behave approximately as if the X-ray pulse were a step function. We also present the solution for this case.

The scaled equations controlling the boundary layer were presented in Reference 1. There it was shown that if the X-ray pulse rises in time

[1] Longmire, C. L., and N. J. Carron, Scaling of the Time-Dependent SGEMP Boundary Layer, Mission Research Corporation, MRC-R-262, DNA 3975T, April 1976 (U).

like a power of time

$$F = R_p t^p \tag{1}$$

where

$$0 \le p < \infty \quad , \tag{2}$$

$F$ is the incident flux (cal/cm$^2$/sec), and $R_p$ a constant, then the solution scales completely. For a given electron energy spectrum and given $p$, a single solution suffices for all $R_p$. The solutions given here correspond to $p = 1$ ($R_1$ is the flux rise rate) and $P=0$ ($R_o$ is the constant flux).

The solution is a one-dimensional one and should be meaningful out to distances small compared to the lateral dimensions of the target.

We give plots of electric field, potential, number density, and current density as a function of position and time. These are presented both as a function of $x$ (distance from the target surface) for various times, and as a function of time for various $x$. In addition the dipole moment per unit area of the layer, and its first and second time derivatives are given as a function of time. The spatial integral of the current density is the same as the time derivative of the dipole moment.

The current densities given here may be useful as prescribed currents in Maxwell solving codes. The second time derivative of the dipole moment may be useful for estimating dipole radiation. The dipole moment may be useful for estimating distant quasi-static dipole fields.

## SECTION 2
## COMPUTATION METHOD

The numerical solutions were obtained with the one dimensional particle moving code SCAL1D.[2] Time and length scales are determined by the naturally occurring electron plasma properties. Times are measured as multiples of an effective plasma period $T_p$ given by

$$T_p = \sqrt{\frac{m}{4\pi e^2 N_1}} \tag{3}$$

where m(e) is the electron mass (charge) and $N_1$ is an average surface number density, and lengths are measured as multiples of an effective plasma Debye length

$$\lambda = \bar{v}\, T_p \tag{4}$$

where $\bar{v}$ is the average normal velocity of the emitted electrons. These times and lengths are scaled out before beginning computation, so computed times and lengths are on the order of unity. Similarly the dependent dynamical variables have a natural magnitude which is factored out.

If the pulse is linearly rising, $N_1$ in Equation (3) is itself time dependent, so that Equation (3) as it stands does not define a time unit. In the general case, Reference 1 shows that a plasma period can be taken to be

---

[2] Carron, N. J., Description of the Code SCAL1D for Calculating the One-Dimensional SGEMP Boundary Layer, Mission Research Corporation, MRC-R-267, May 1976 (U).

$$T_p = \left[\frac{m\,\bar{v}}{4\pi e^2 Y\, R_p}\right]^{\frac{1}{2+p}} \qquad (5)$$

where Y is the material yield (elec/cal).

We assume the emitted electrons have a $\cos\theta$ angular distribution, where $\theta$ is the polar angle measured from the normal. The shapes of the two energy spectra we consider are shown in Figure 1. If the electron energy spectrum is exponential

$$\frac{dn}{dE} \sim \frac{1}{\bar{E}}\, e^{-E/\bar{E}} \qquad \text{(elec/keV)} \qquad (6)$$

where E is the electron energy and $\bar{E}$ is the exponentiation energy, then the average normal velocity is

$$\bar{v} = \sqrt{\frac{2\pi\,\bar{E}}{9m}} \quad . \qquad (7)$$

If the spectrum is linear-times-exponential

$$\frac{dn}{dE} \sim \frac{E}{\bar{E}^2}\, e^{-E/\bar{E}} \cdot \text{(elec/keV)} \quad , \qquad (8)$$

then

$$\bar{v} = \sqrt{\frac{\pi}{2}\frac{\bar{E}}{m}} \qquad (9)$$

In the code we have chosen a very small time step, $\lesssim 0.02\,T_p$. At all interesting times there were several thousand particles in the first few Debye lengths. The particles were given a finite length of 0.2 Debye length for the purpose of computing the charge density and current density.

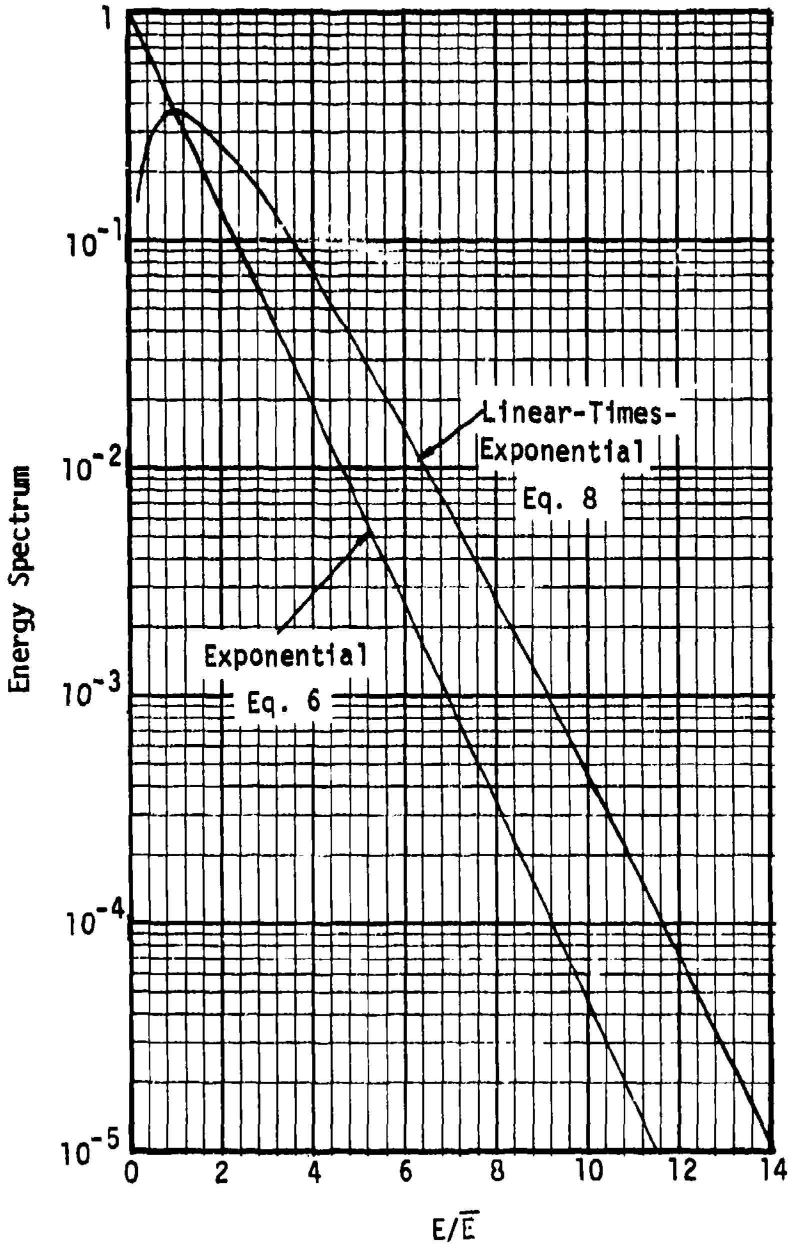



Figure 1. Exponential, and linear-times-exponential energy spectra.

These quantities were further averaged over three spatial cells with a simple weighting scheme. The cell size was $\sim 0.1$ Debye length, and there were always several hundred particles in each cell.

The current density $J(x,t)$ was computed as the sum of particle weights times their velocities, rather than as $\partial E/\partial t$ where $E$ is the electric field. At later times when $J$ is small and due to approximately equal numbers of particles with positive and negative velocities, irregularities and oscillations occurred whose precise value was dependent on the time step, emission particle weighting scheme, etc. In the plots presented here we show an average smooth dashed line through these unreliable values. The plots of current density vs. time at various $x$ were sometimes constructed from $\partial E/\partial t$ when this method was more reliable.

## SECTION 3
## LINEARLY RISING PULSE, EXPONENTIAL SPECTRUM

In this section we present results for a linearly rising time history $(p=1)$ and for the exponential energy spectrum, Equation (6).

In the following equations we give dimensional units for the dynamical variables. When numbers are given in the equations, we use these units for $\overline{E}$, $Y$, and $R_1$:

| | |
|---|---|
| Electron exponentiation energy | $\overline{E}$ (keV) |
| Yield | $Y$ (elec/cal) |
| X-ray rise rate | $R_1$ (cal/cm$^2$/sec$^2$) |

Equations (5) and (7) show the time unit to be

$$T_p = \left[\frac{\sqrt{m\,\overline{E}}}{6\sqrt{2\pi}\, e^2\, Y\, R_1}\right]^{1/3}$$

$$= 0.7035 \left[\frac{\sqrt{\overline{E}}}{Y\, R_1}\right]^{1/3} \quad \text{sec} \qquad (10)$$

and the unit of length, Equation (4), is

$$\lambda = 7.796 \times 10^8 \left[\frac{\overline{E}^2}{Y\, R_1}\right]^{1/3} \quad \text{cm} \qquad (11)$$

The units of electric field $(E_1)$ and potential $(\Phi_1)$ are taken to be

$$E_1 = \frac{m\,\overline{v}}{e\,T_p}$$

$$= 8.955 \times 10^{-5} \left[\overline{E}\ Y\ R_1\right]^{1/3} \quad \text{Volts/m} \quad , \qquad (12)$$

$$\Phi_1 = \lambda\ E_1 = \frac{2\pi}{9}\frac{\overline{E}}{e}$$

$$= 698\ \overline{E} \quad \text{Volts} \qquad (13)$$

The units of number density $(N_1)$ and current density $(J_1)$ are

$$N_1 = \frac{Y\ R_1\ T_p}{\overline{v}} = 6.349 \times 10^{-10} \left[\frac{Y^2\ R_1^2}{\overline{E}}\right]^{1/3} \quad \text{cm}^{-3} \quad , \qquad (14)$$

$$J_1 = e\ N_1\ \overline{v} = 1.126 \times 10^{-15}\left[\sqrt{\overline{E}}\ \ Y^2\ R_1^2\right]^{1/3} \quad \text{Amps/m}^2 \ . \qquad (15)$$

The units of dipole moment per unit area $(P_1)$ and its time derivative $(\dot{P}_1)$ are

$$P_1 = e\ \lambda^2\ N_1 = \frac{\overline{E}}{18e}$$

$$= 6.181 \times 10^{-9}\ \overline{E} \quad \text{Coul/m} \quad , \qquad (16)$$

$$\dot{P}_1 = \frac{P_1}{T_p} = 8.786 \times 10^{-9} \left[\overline{E}^{5/2}\ Y\ R_1\right]^{1/3} \quad \text{Amps/m} \quad . \qquad (17)$$

Finally, the second time derivative of the dipole moment per unit area has unit

$$\ddot{P}_1 = \frac{P_1}{T_p^2} = 1.249 \times 10^{-8} \left[\overline{E}\ Y\ R_1\right]^{2/3} \quad \text{Amps/m/sec} \qquad (18)$$

For example, if $\bar{E} = 5$ keV, the material yield is $Y = 5 \times 10^{12}$ elec/cal, and the flux is rising at a rate $R_1 = 10^{13}$ cal/cm$^2$/sec$^2$, then

$$T_p = 2.50 \text{ ns}$$

$$\lambda = 6.19 \text{ cm}$$

$$E_1 = 5.64 \times 10^4 \text{ V/m}$$

$$\Phi_1 = 3.49 \text{ kV}$$

$$N_1 = 5.04 \times 10^7 \text{ cm}^{-3}$$

$$J_1 = 2.00 \times 10^2 \text{ Amps/m}^2$$

$$P_1 = 3.09 \times 10^{-8} \text{ Coul/m}$$

$$\dot{P}_1 = 12.38 \text{ Amps/m}$$

$$\ddot{P}_1 = 4.96 \times 10^9 \text{ Amps/m/sec}$$

Figures 2 through 9 show the electric field, potential, number density, and current density as a function of distance from the surface and time, scaled to $\lambda$ and $T_p$; and Figures 10 through 12 show the layer's dipole moment per unit area and its first two time derivatives. The units are those of Equations (10) through (18).

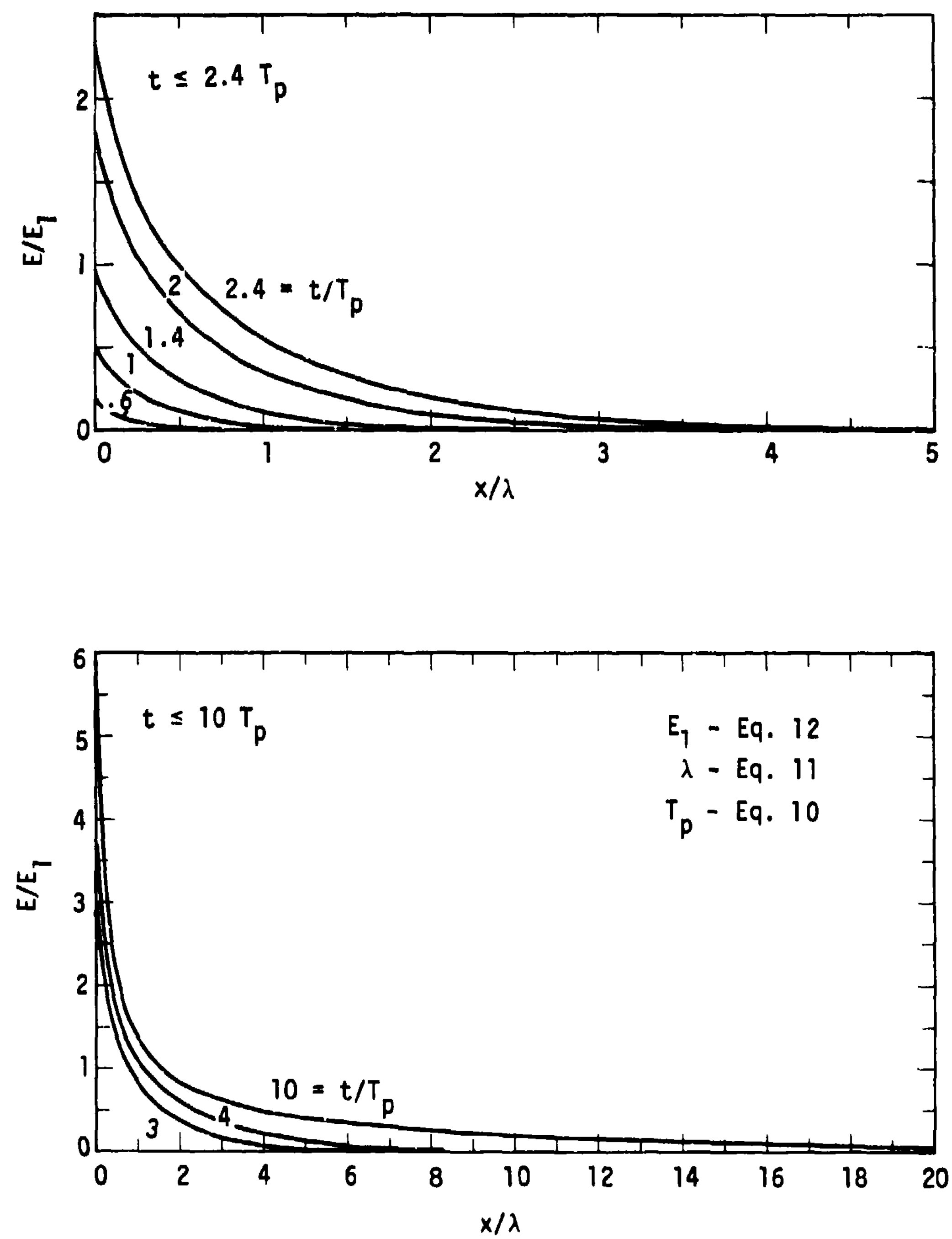



Figure 2. Electric field vs. x at various times.

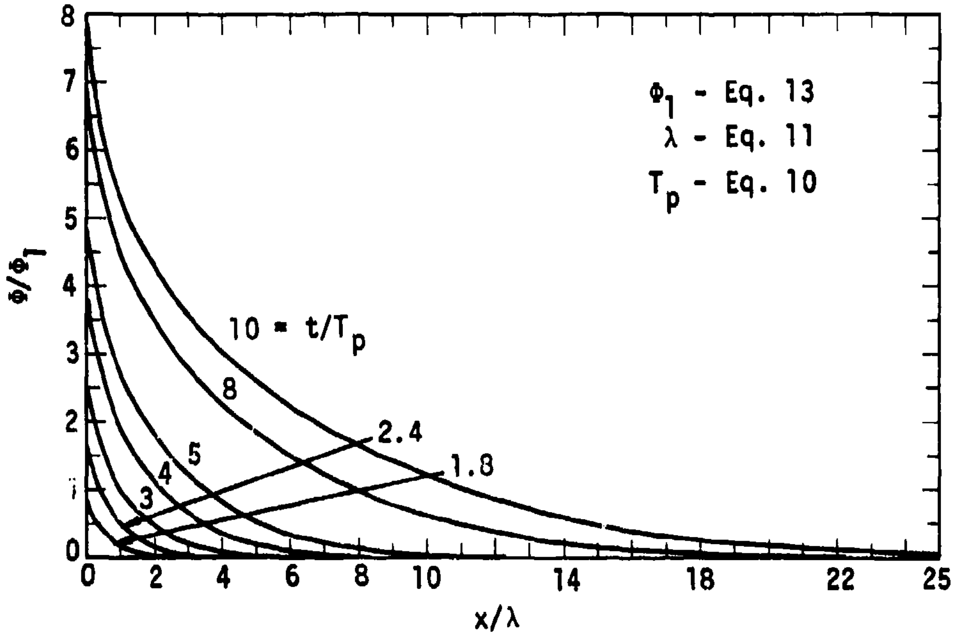



Figure 3. Potential vs. x at various times.

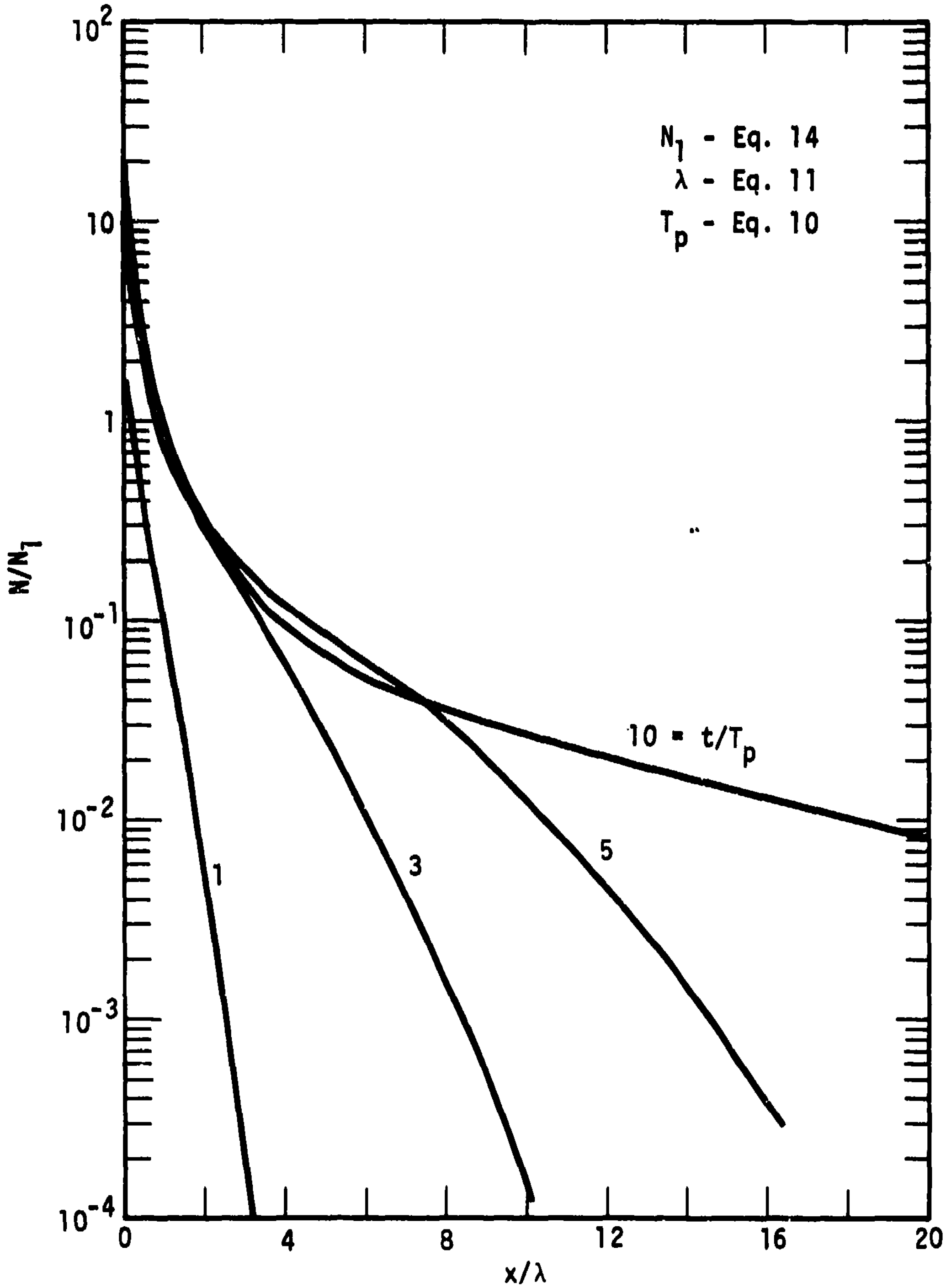
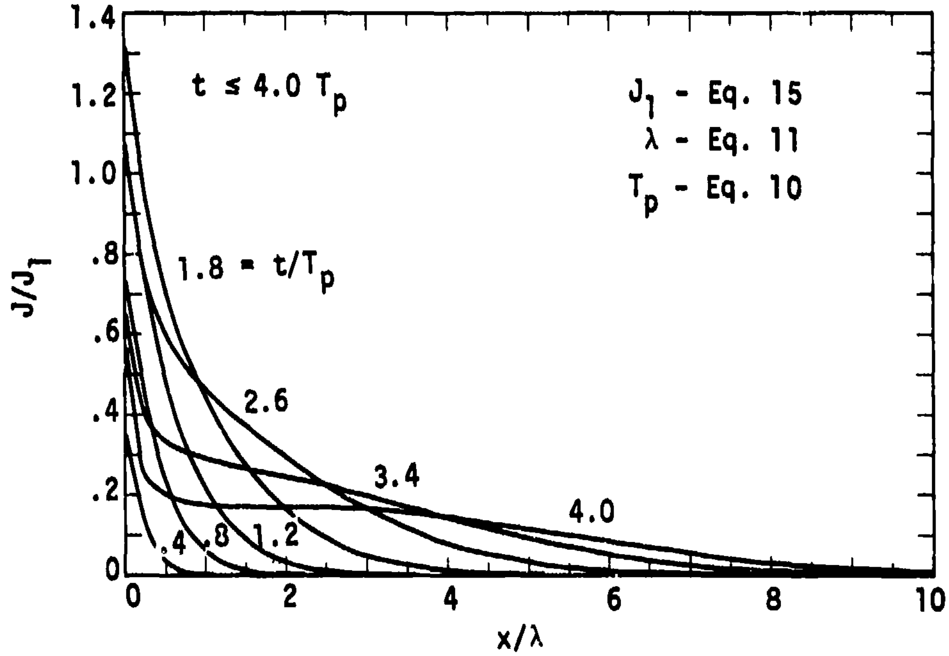



Figure 4. Number density vs. x at various times.



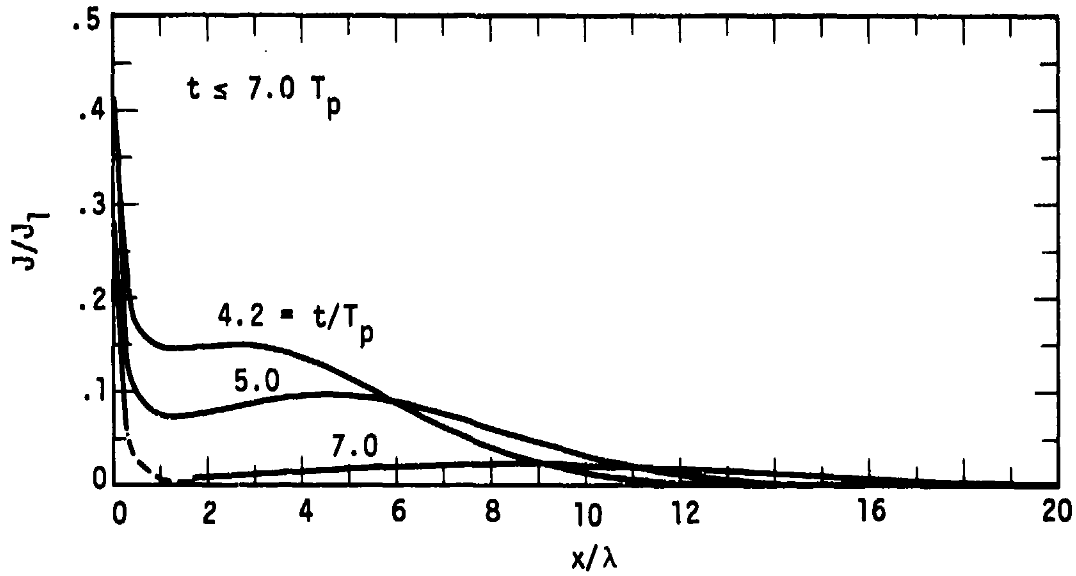




Figure 5. Current density vs. x at various times

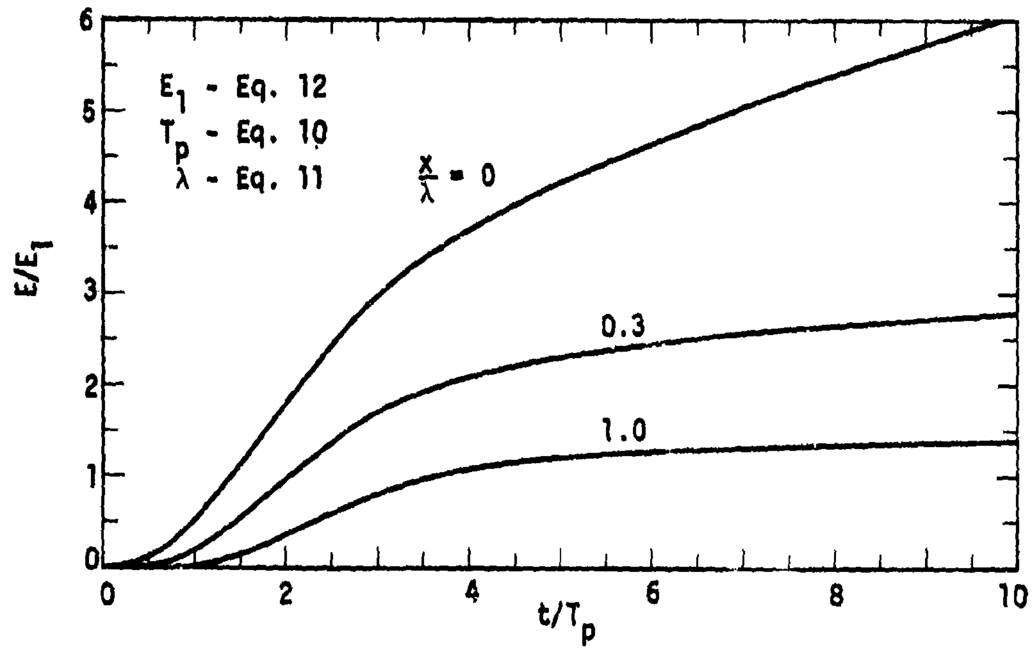



Figure 6. Electric field vs. time at various x.

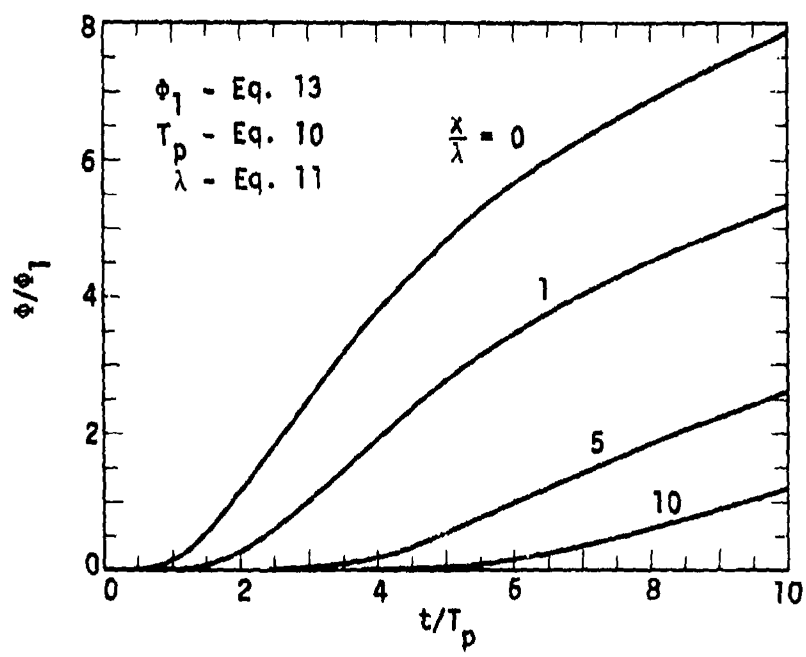



Figure 7. Potential vs. time at various x.

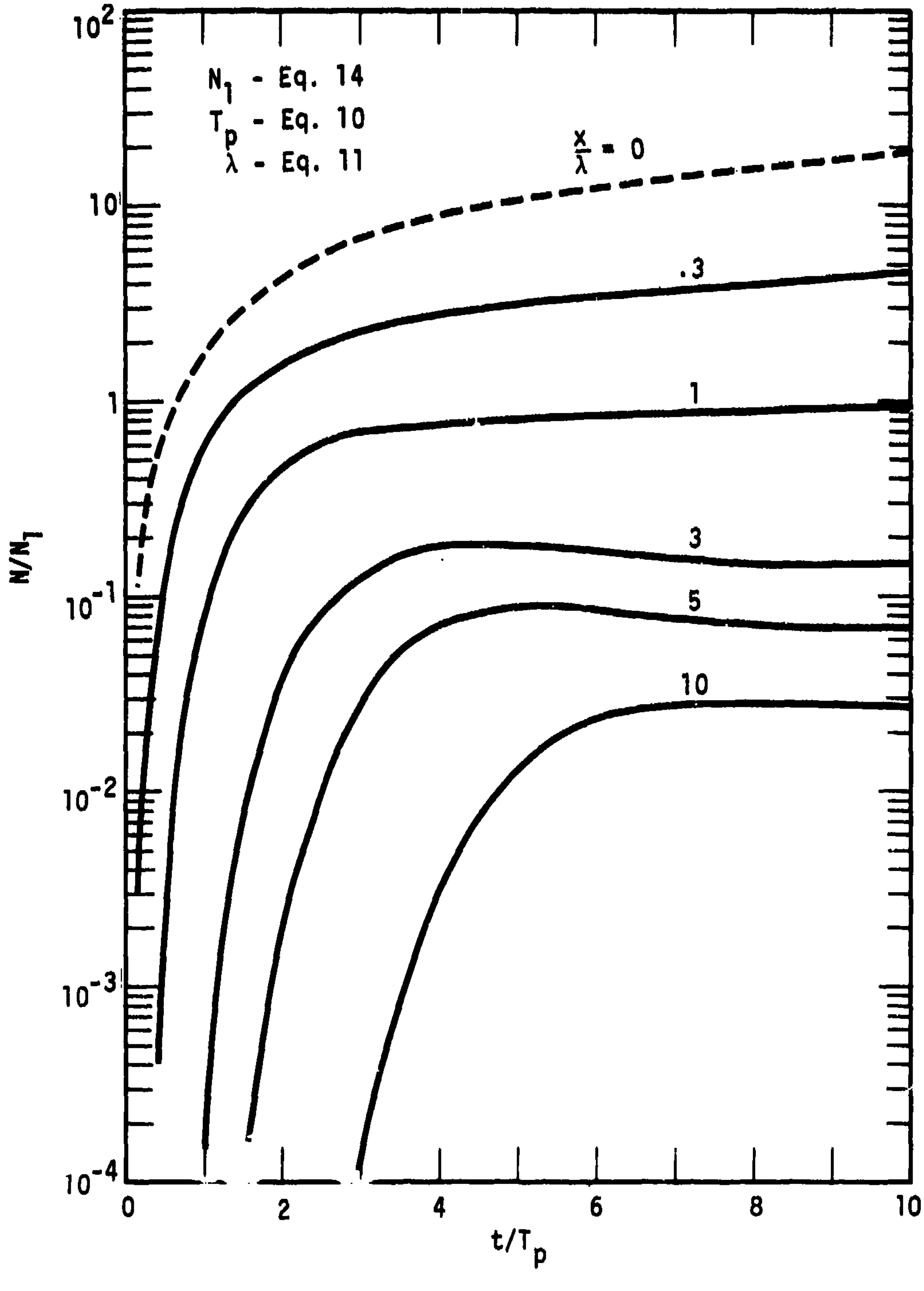



Figure 8. Number density vs. time at various x.

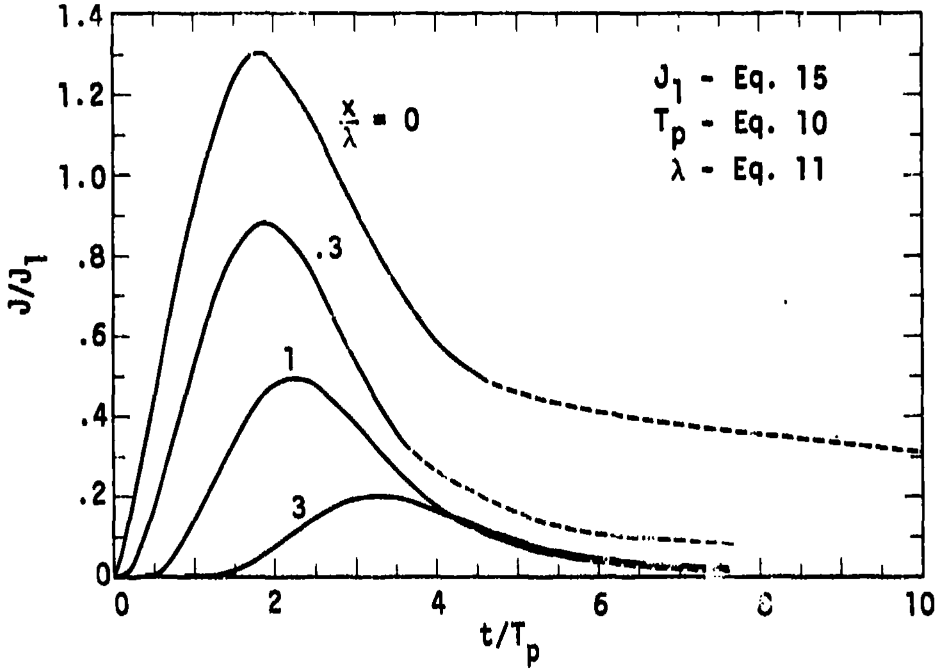



Figure 9. Current density vs. time at various x.

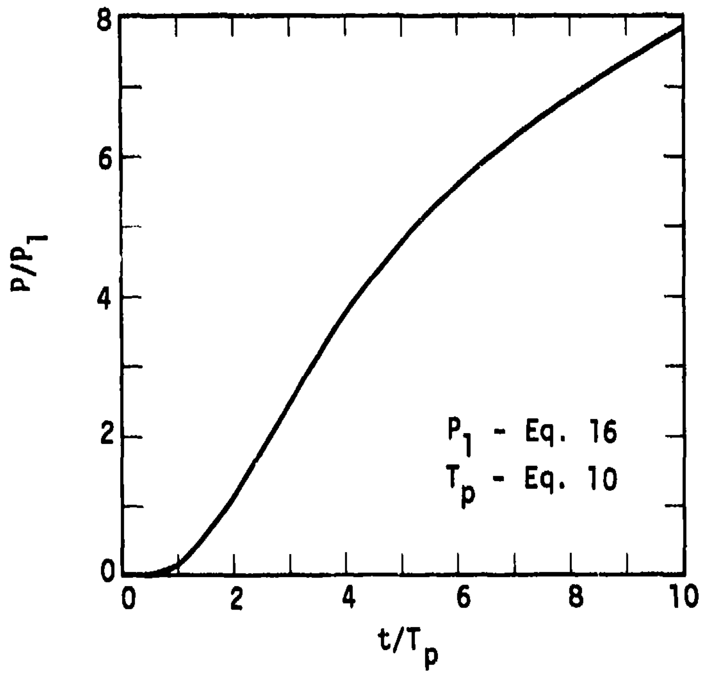



Figure 10. Dipole moment per unit area vs. time.

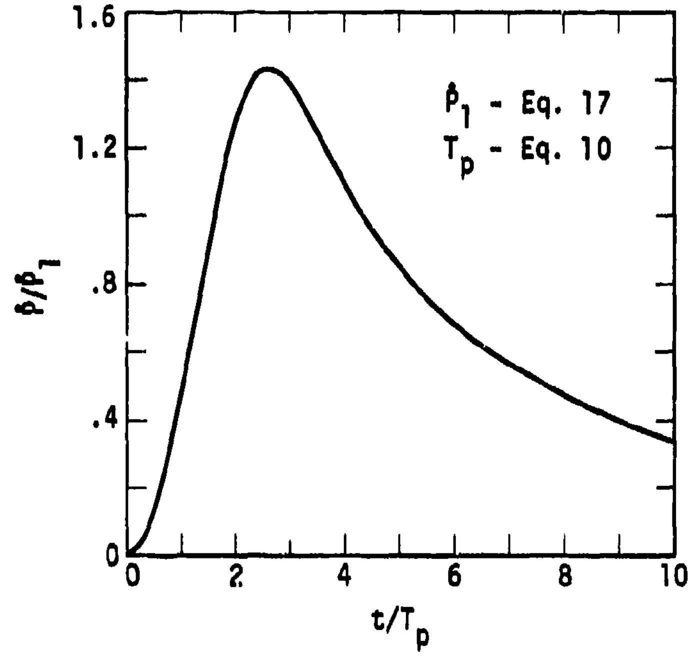



Figure 11. Time derivative of dipole moment vs. time.

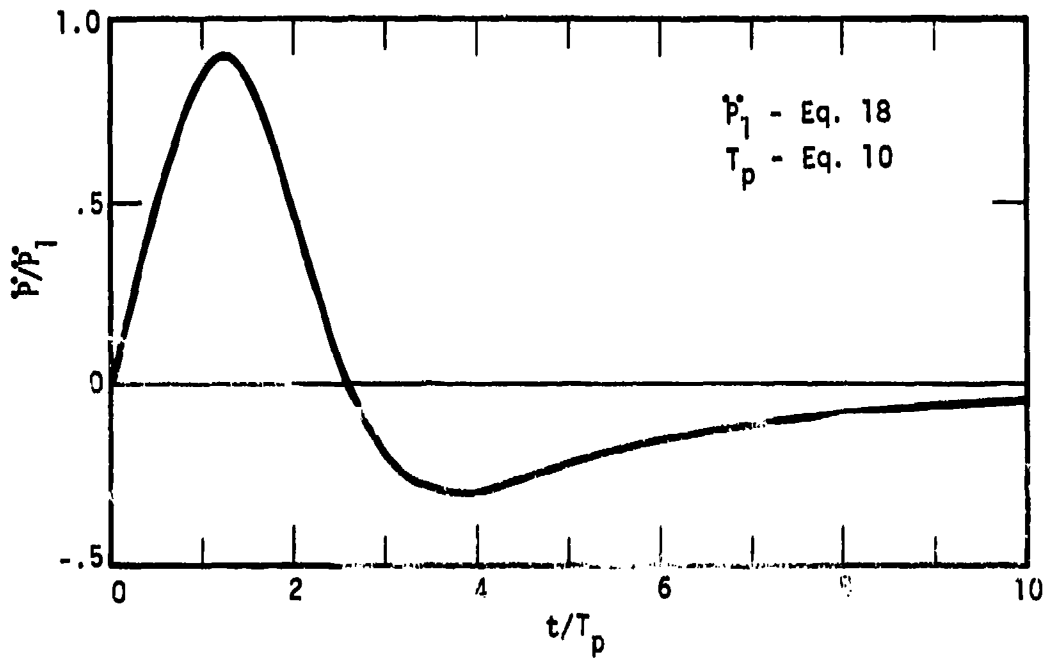



Figure 12. Second time derivative of dipole moment vs. time.

## SECTION 4

## LINEARLY RISING PULSE, LINEAR-TIMES-EXPONENTIAL ENERGY SPECTRUM

This section presents results for a linearly rising time history ($p=1$) and for the linear-times-exponential energy spectrum, Equation (8). $\overline{E}$, Y, and $R_1$ are in the same units as in the previous section (keV, $cal^{-1}$, $cal/cm^2/sec^2$).

Equations (5) and (9) show the time unit to be

$$T_p = \left[\frac{1}{4\sqrt{2\pi}\, e^2} \frac{\sqrt{m\,\overline{E}}}{Y\,R_1}\right]^{1/3}$$

$$= 0.8053 \left[\frac{\sqrt{\overline{E}}}{Y\,R_1}\right]^{1/3} \quad \text{sec} . \qquad (19)$$

and the unit of length is

$$\lambda = \overline{v}\, T_p = \left[\frac{\pi}{16\, e^2\, m} \frac{\overline{E}^2}{Y\,R_1}\right]^{1/3}$$

$$= 1.339 \times 10^9 \left[\frac{\overline{E}^2}{Y\,R_1}\right]^{1/3} \quad \text{cm} \quad . \qquad (20)$$

The units of electric field ($E_1$) and potential ($\Phi_1$) are

$$E_1 = \frac{m}{e}\frac{\overline{v}}{T_p} = \left[2\pi^2 \frac{m}{e}\, \overline{E}\, Y\, R_1\right]^{1/3}$$

$$= 1.173 \times 10^{-4} \left[\overline{E}\, Y\, R_1\right]^{1/3} \quad \text{Volts/m} \quad , \qquad (21)$$

$$\Phi_1 = \lambda\, E_1 = \frac{\pi}{2}\frac{\overline{E}}{e}$$

$$= 1.571 \times 10^3\, \overline{E} \quad \text{Volts} \quad . \tag{22}$$

The units of number density $(N_1)$ and current density $(J_1)$ are

$$N_1 = \frac{Y\, R_1\, T_p}{\overline{v}}$$

$$= 4.845 \times 10^{-10} \left[\frac{Y^2\, R_1^2}{\overline{E}}\right]^{1/3} \text{cm}^{-3} \quad , \tag{23}$$

$$J_1 = e\, N_1\, \overline{v}$$

$$= 1.290 \times 10^{-15} \left[\sqrt{\overline{E}}\; Y^2\, R_1^2\right]^{1/3} \text{Amps/m}^2 \tag{24}$$

The units of dipole moment per unit area $(P_1)$ and its time derivative $(\dot{P}_1)$ are

$$P_1 = e\, \lambda^2\, N_1 = \frac{\overline{E}}{8e}$$

$$= 1.391 \times 10^{-8}\, \overline{E} \quad \text{Coul/m} \quad , \tag{25}$$

$$\dot{P}_1 = \frac{P_1}{T_p} = 1.727 \times 10^{-8} \left[\overline{E}^{5/2}\, Y\, R_1\right]^{1/3} \text{Amps/m} \tag{26}$$

The units of second time derivative of the dipole moment per unit area is

$$\ddot{P}_1 = \frac{\dot{P}_1}{T_p} = 2.144 \times 10^{-8} \left[\overline{E}\, Y\, R_1\right]^{2/3} \text{Amps/m/sec} \; . \tag{27}$$

Figures 13 through 23 show the dynamical solutions for the case of a linearly rising time history and a linear-times-exponential energy spectrum, using the units of Equations (19) through (27).

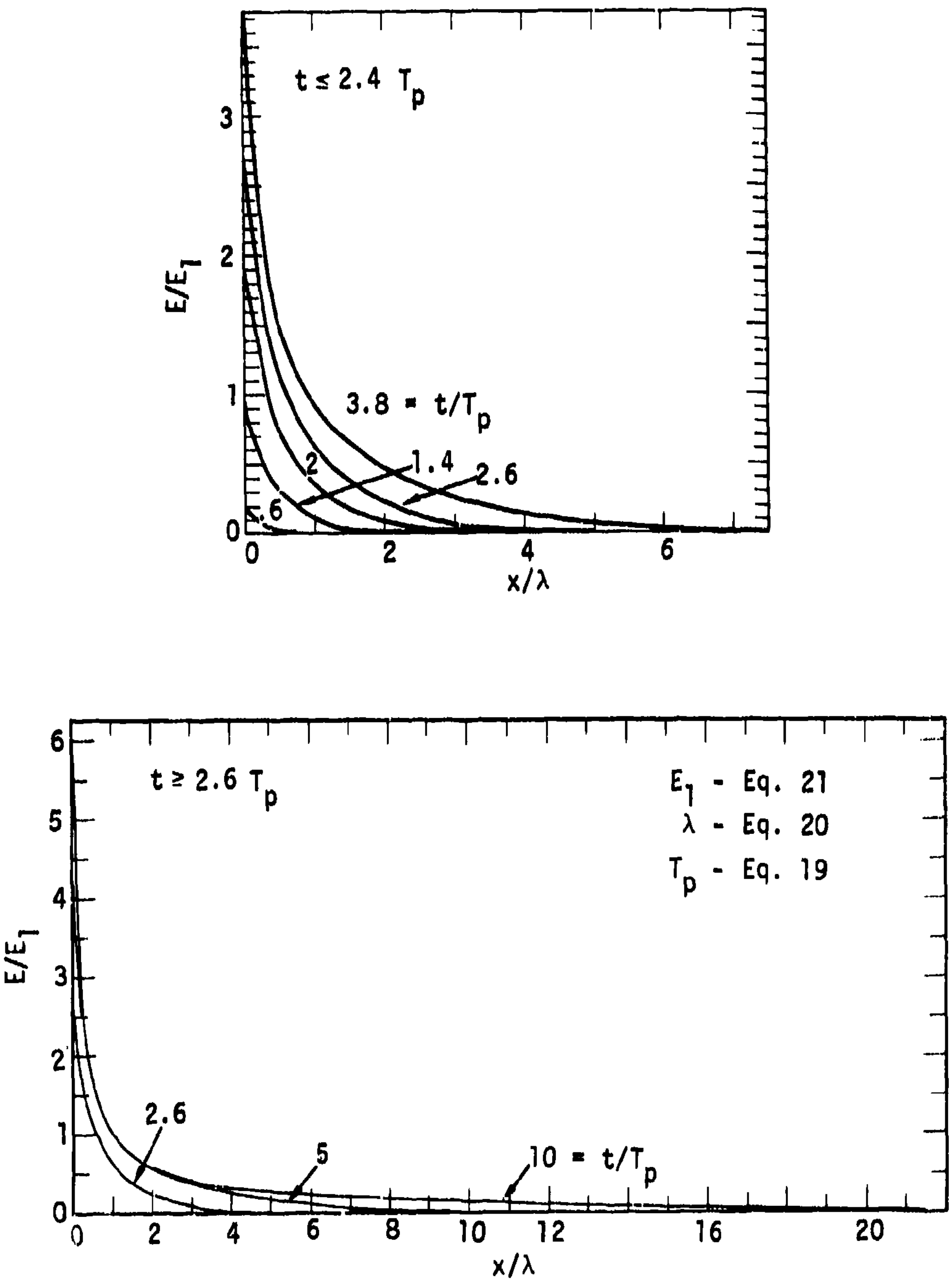



Figure 13. Electric field vs. x at various times.

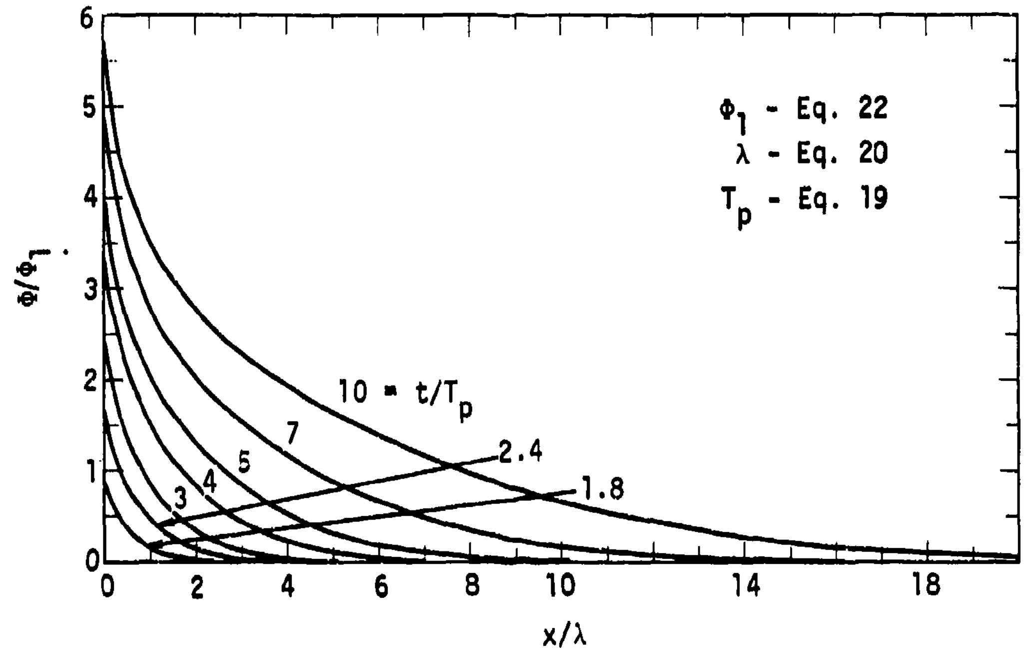



Figure 14. Potential vs. x at various times.

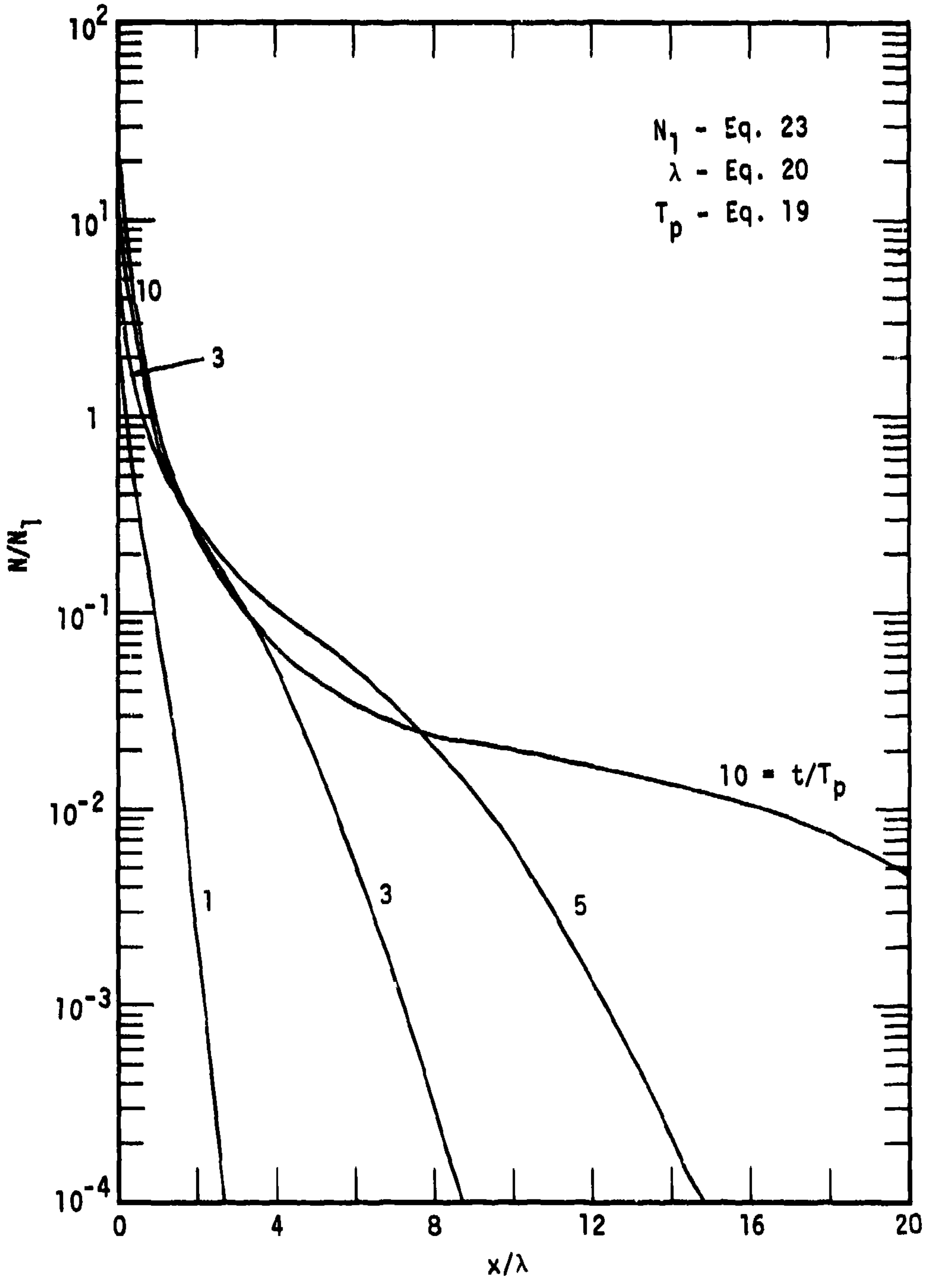



Figure 15. Number density vs. x at various times.

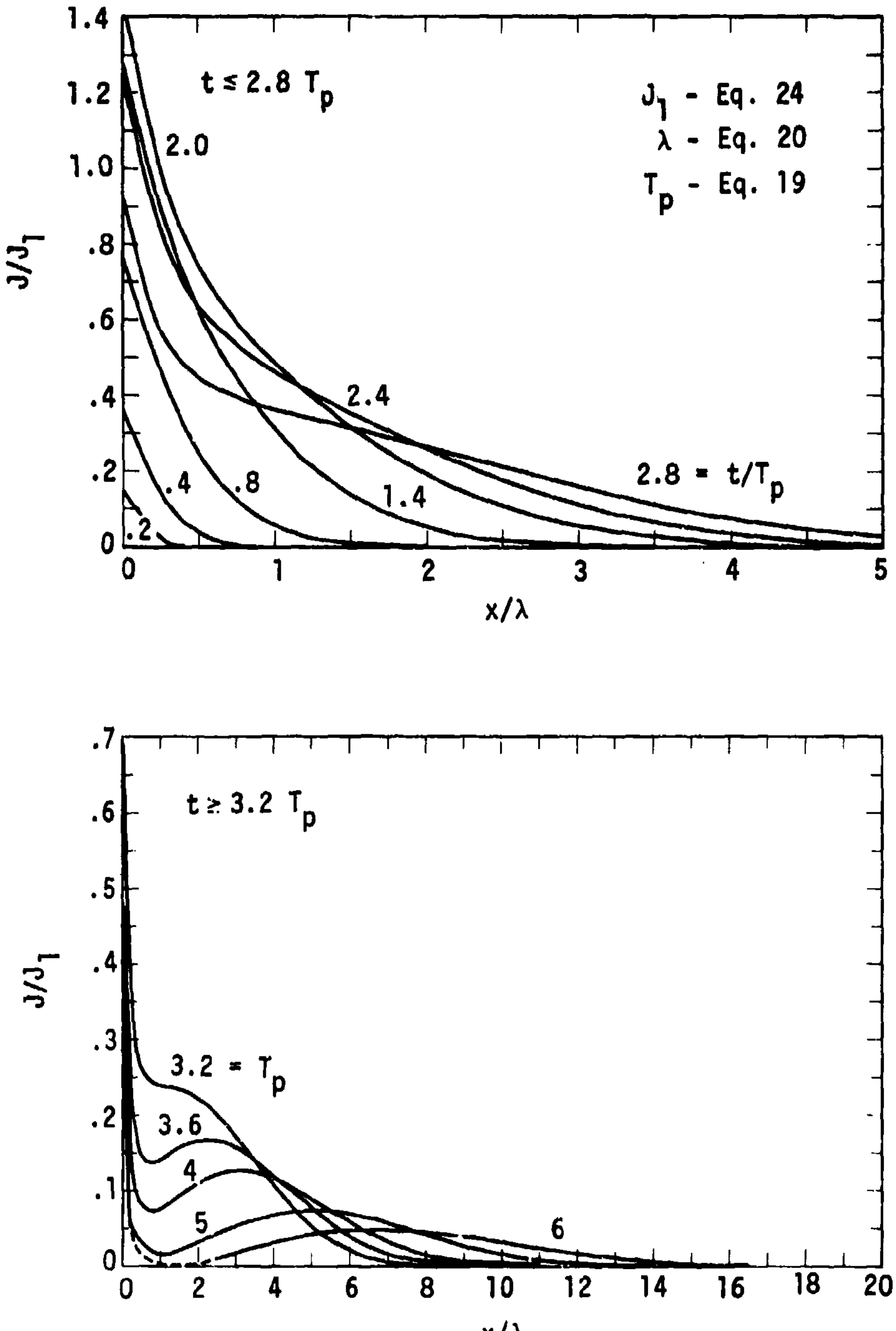



Figure 16. Current density vs. x at various times.

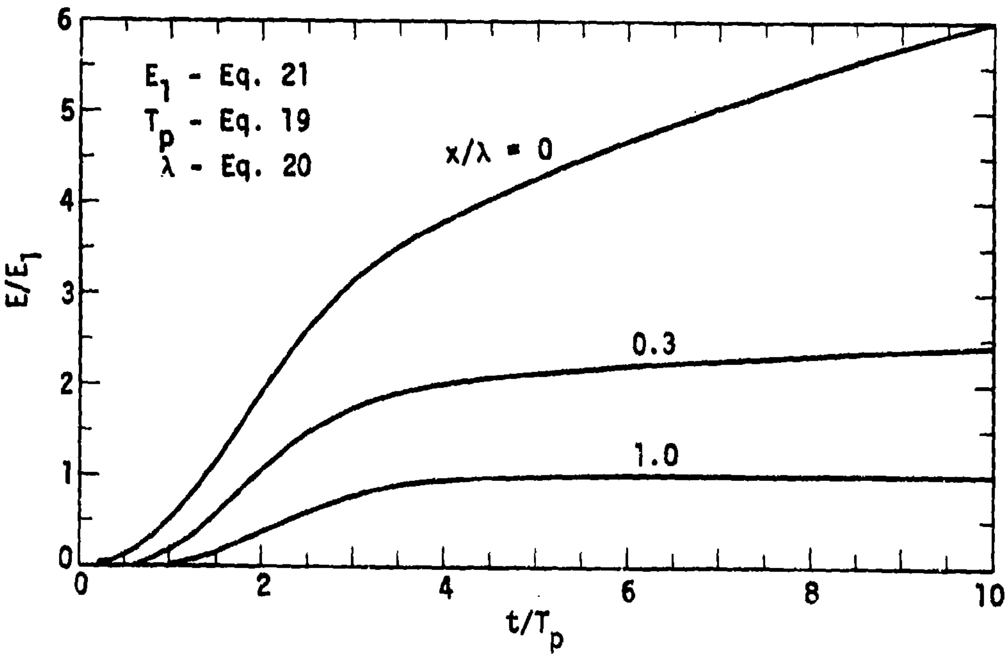



Figure 17. Electric field vs. time at various x.

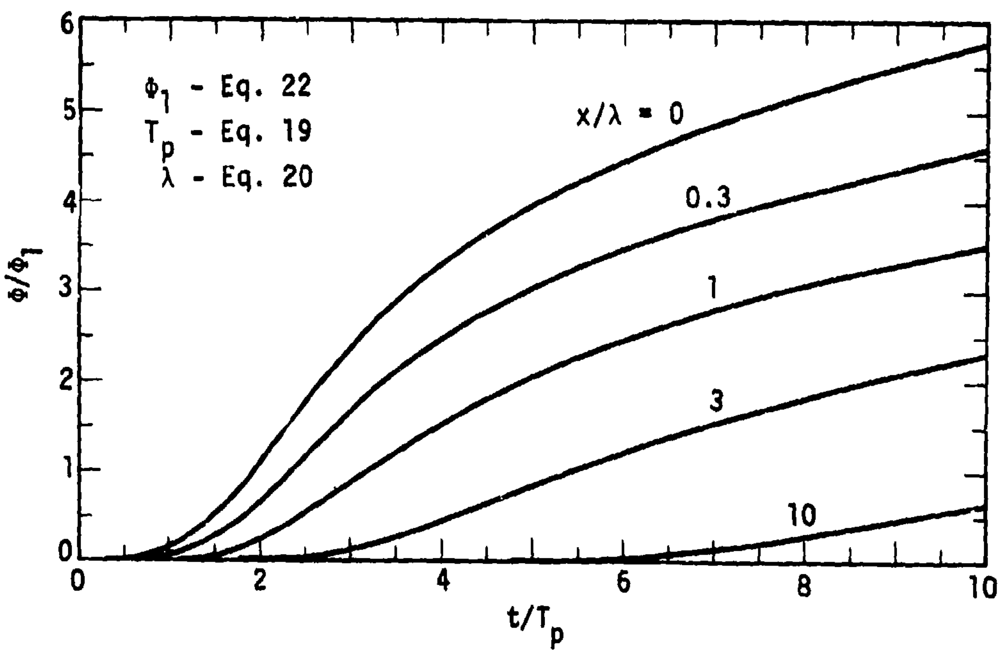



Figure 18. Potential vs. time at various x.

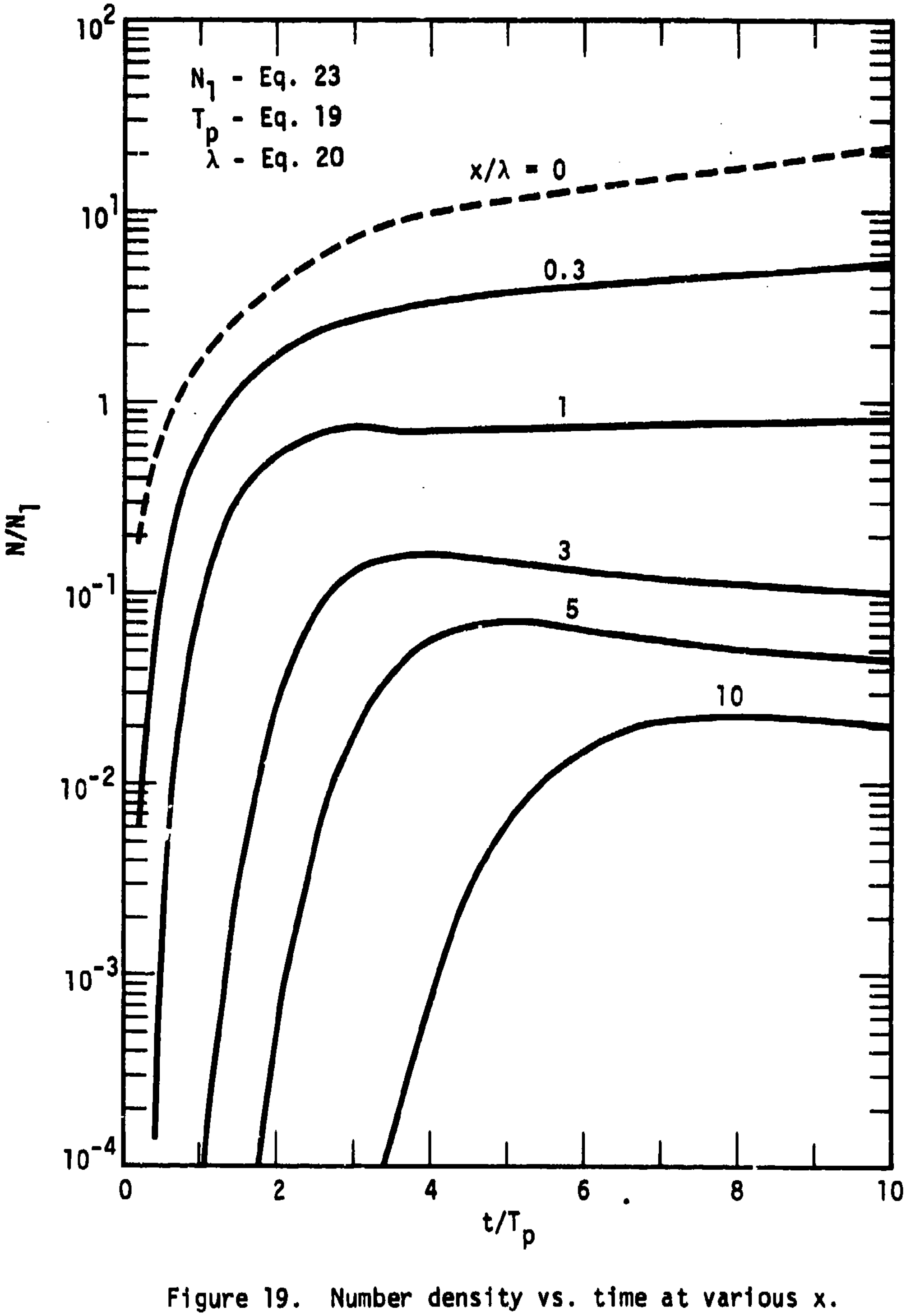



Figure 19. Number density vs. time at various x.

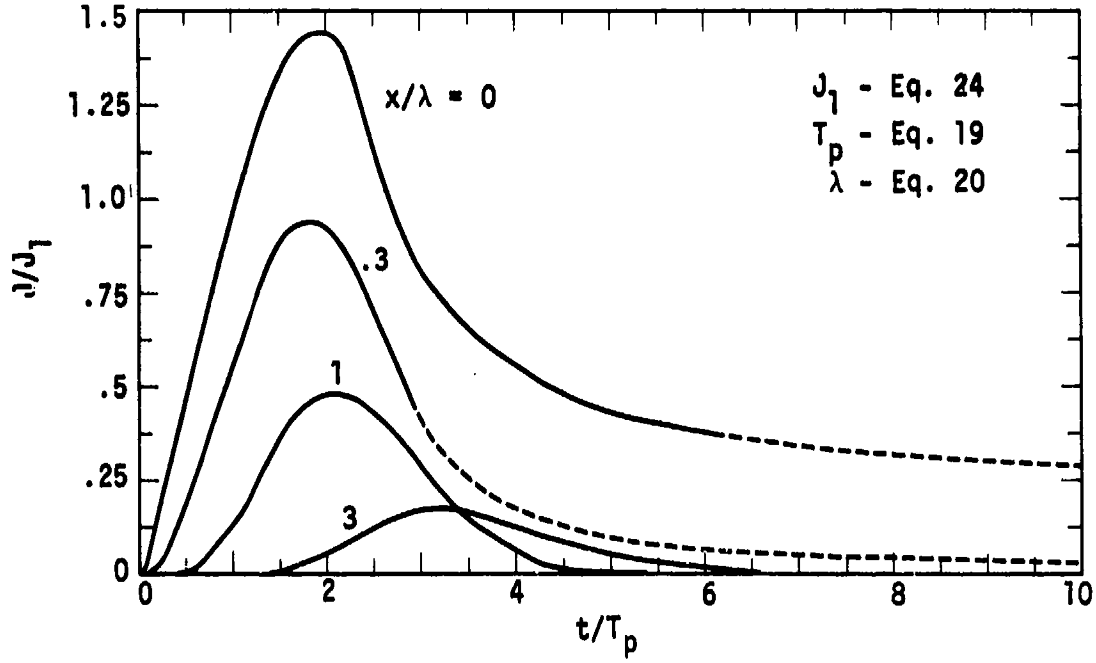



Figure 20. Current density vs. time at various x.

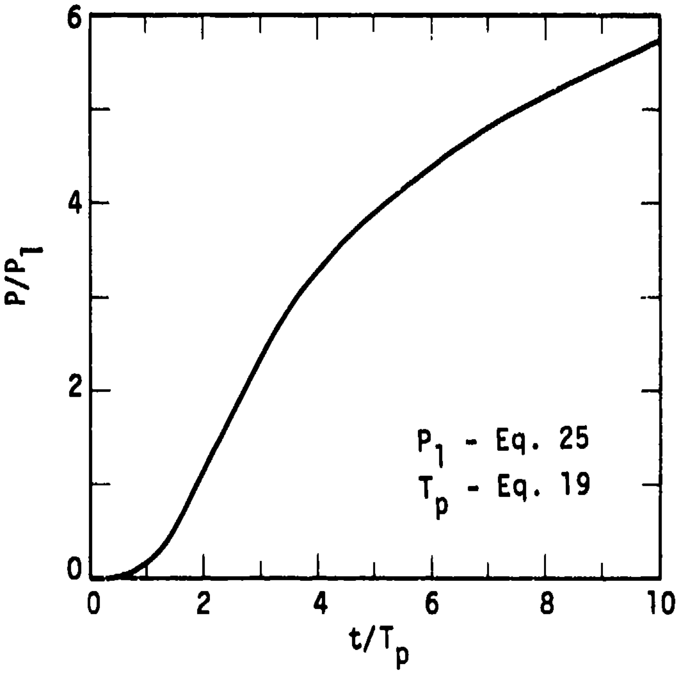



Figure 21. Dipole moment per unit area vs. time

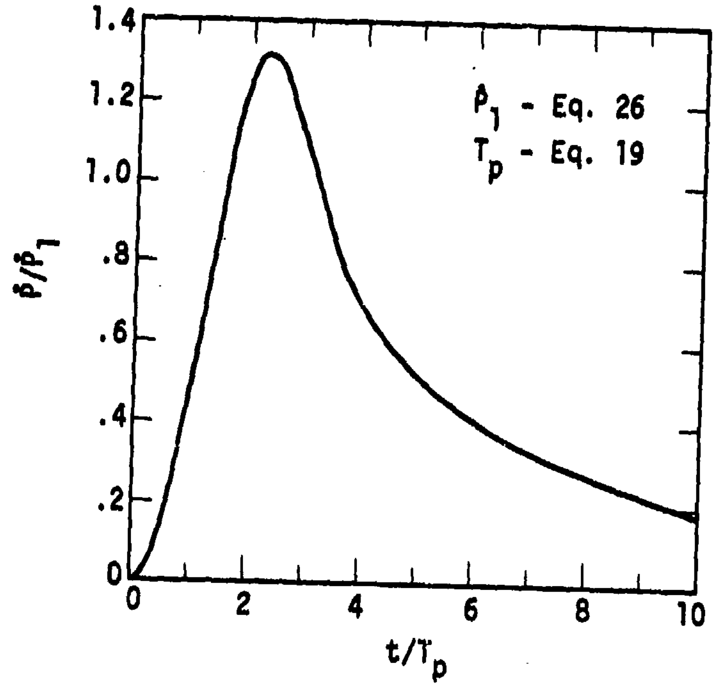



Figure 22. Time derivative of dipole moment vs. time.

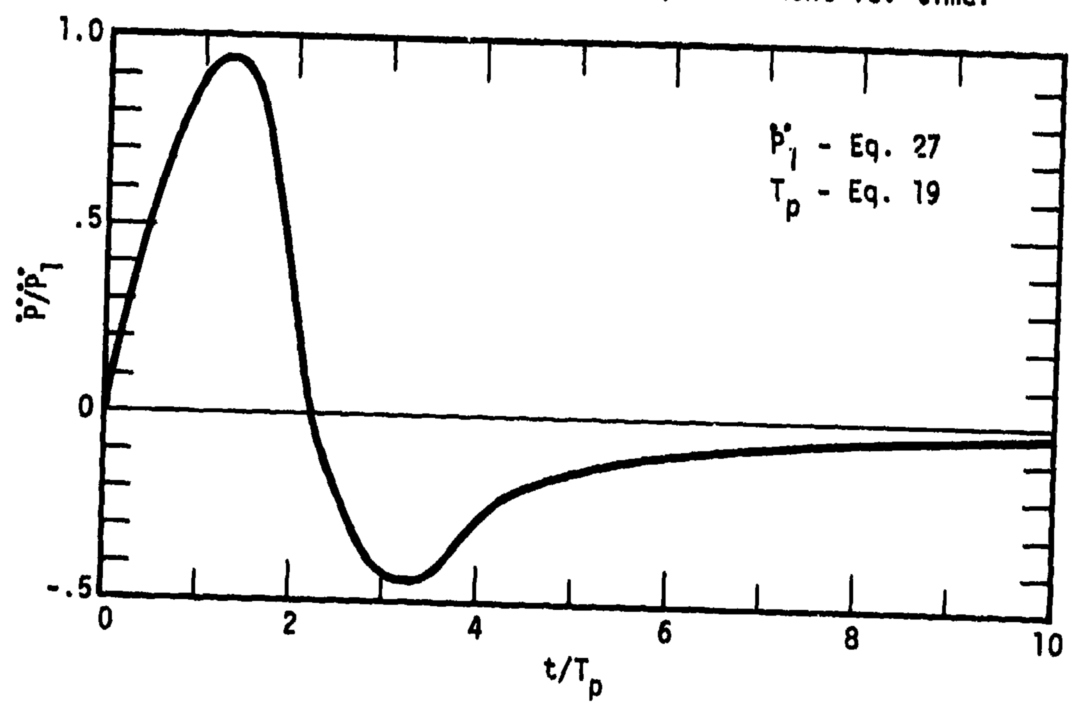



Figure 23. Second time derivative of dipole moment vs. time.

## SECTION 5
## CONSTANT PULSE, EXPONENTIAL SPECTRUM

In this section we present results for a constant X-ray pulse ($p=0$) and for the exponential energy spectrum, Equation (6).

We give here the dimensional units for the dynamical variables. When numbers are given we use these units for $\bar{E}$, Y, and $R_o$:

| | |
|---|---|
| Electron exponentiation energy | $\bar{E}$ (keV) |
| Yield | Y (elec/cal) |
| X-ray flux | $R_o$ (cal/cm$^2$/sec) . |

Equations (5) and (7) show the time unit to be

$$T_p = \left[\frac{\sqrt{m\,\bar{E}}}{6\sqrt{2\pi}\,e^2\;Y\;R_o}\right]^{1/2} ,$$

$$= 0.5901\left[\frac{\sqrt{\bar{E}}}{Y\;R_o}\right]^{1/2} \quad \text{sec} \quad , \tag{28}$$

and the unit of length is

$$\lambda = \frac{1}{3}\left[\frac{1}{3}\sqrt{\frac{\pi}{2m}}\;\frac{\bar{E}^{3/2}}{e^2\;Y\;R_o}\right]^{1/2}$$

$$= 6.539 \times 10^8\left[\frac{\bar{E}^{3/2}}{Y\;R_o}\right]^{1/2} \quad \text{cm} \tag{29}$$

The units of electric field $(E_1)$ and potential $(\Phi_1)$ are

$$E_1 = \frac{m\,\overline{v}}{e\,T_p} = 1.068 \times 10^{-4} \left[\sqrt{\overline{E}}\, Y\, R_o\right]^{1/2} \text{ V/m} , \tag{30}$$

$$\Phi_1 = \lambda\, E_1 = \frac{2\pi}{9} \frac{\overline{E}}{e} = 698\, \overline{E} \quad \text{Volts} . \tag{31}$$

The units of number density $(N_1)$ and current density $(J_1)$ are

$$N_1 = \frac{Y\, R_o}{\overline{v}} = 9.025 \times 10^{-10}\, \frac{Y\, R_o}{\sqrt{\overline{E}}} \text{ cm}^{-3} , \tag{32}$$

$$J_1 = e\, N_1\, \overline{v} = 1.602 \times 10^{-15}\, Y\, R_o \quad \text{Amps/m}^2 \tag{33}$$

The units of dipole moment per unit area $(P_1)$ and its time derivative $(\dot{P}_1)$ are

$$P_1 = e\, \lambda^2\, N_1 = \frac{\overline{E}}{18\, e}$$

$$= 6.181 \times 10^{-9}\, \overline{E} \quad \text{Coul/m} , \tag{34}$$

$$\dot{P}_1 = \frac{P_1}{T_p} = 1.047 \times 10^{-8} \left[\overline{E}^{3/2}\, Y\, R_o\right]^{1/2} \quad \text{Amps/m} \tag{35}$$

The second time derivative of the dipole moment per unit area $(\ddot{P}_1)$ has unit

$$\ddot{P}_1 = \frac{\dot{P}_1}{T_p} = 1.775 \times 10^{-8} \sqrt{\overline{E}}\; Y\, R_o \quad \text{Amps/m/sec} \tag{36}$$

For example if $\overline{E} = 5$ keV, $Y = 10^{13}$ elec/cal, and the flux is $R_o = 10^5$ cal/cm$^2$/sec, then

$$T_p = 0.88 \text{ ns}$$
$$\lambda = 2.19 \text{ cm}$$
$$E_1 = 1.60 \times 10^5 \text{ V/m}$$
$$\Phi_1 = 3.49 \text{ kV}$$
$$N_1 = 4.04 \times 10^8 \text{ cm}^{-3}$$
$$J_1 = 1.60 \times 10^3 \text{ Amps/m}^2$$
$$P_1 = 3.09 \times 10^{-8} \text{ Coul/m}$$
$$\dot{P}_1 = 35.01 \text{ Amps/m}$$
$$\ddot{P}_1 = 3.97 \times 10^{10} \text{ Amps/m/sec} .$$

Figures 24 through 34 give the dynamical solutions for the case of a constant X-ray pulse starting at $t=0$ and an exponential electron energy spectrum. The units are those of Equations (28) through (36).

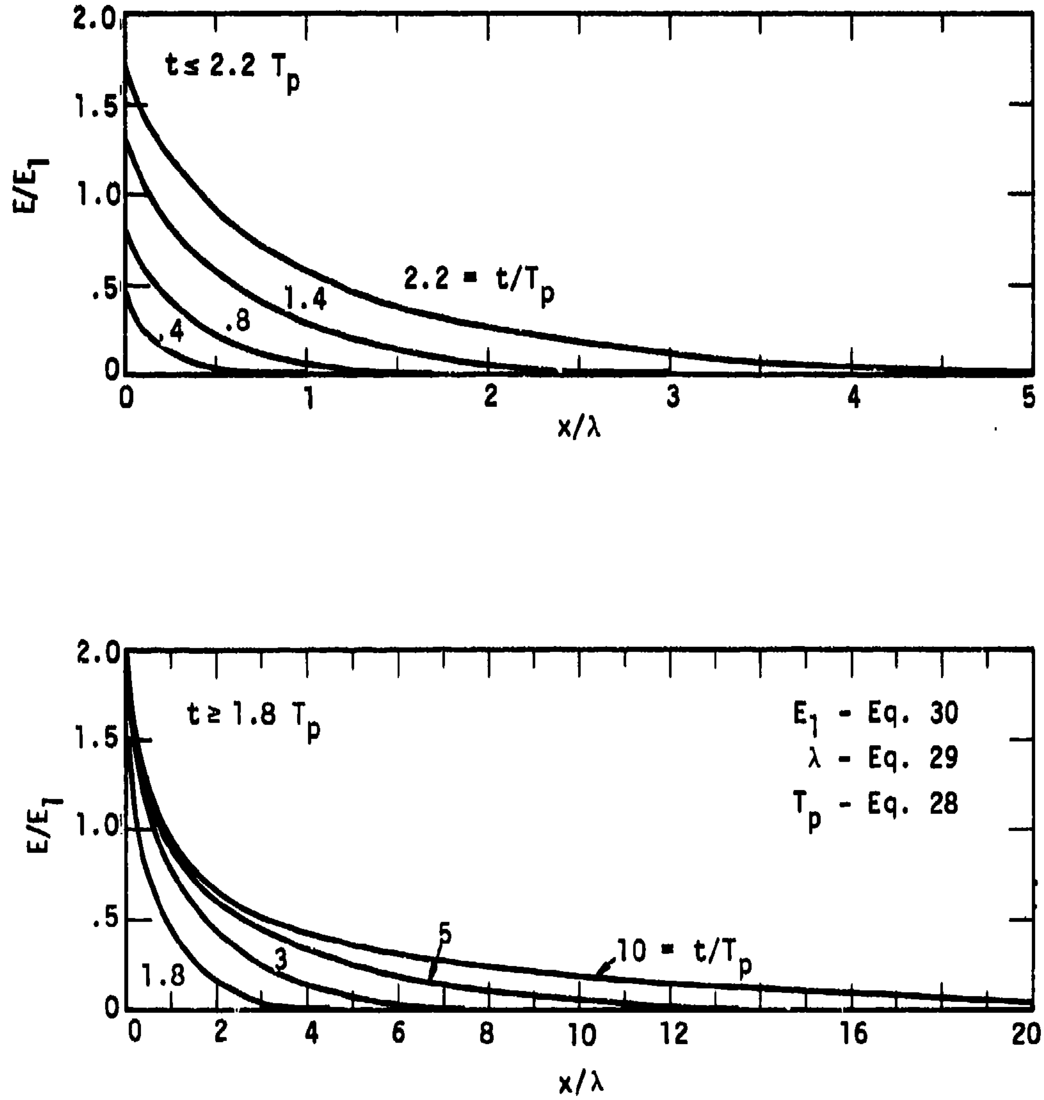



Figure 24. Electric field vs. x at various times.

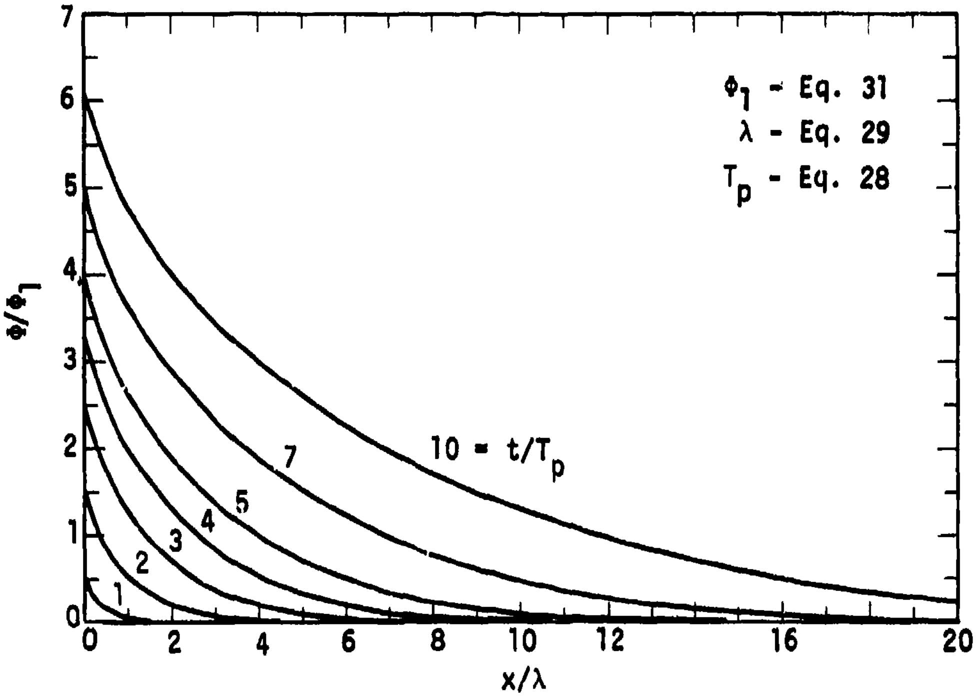



Figure 25. Potential vs. x at various times.

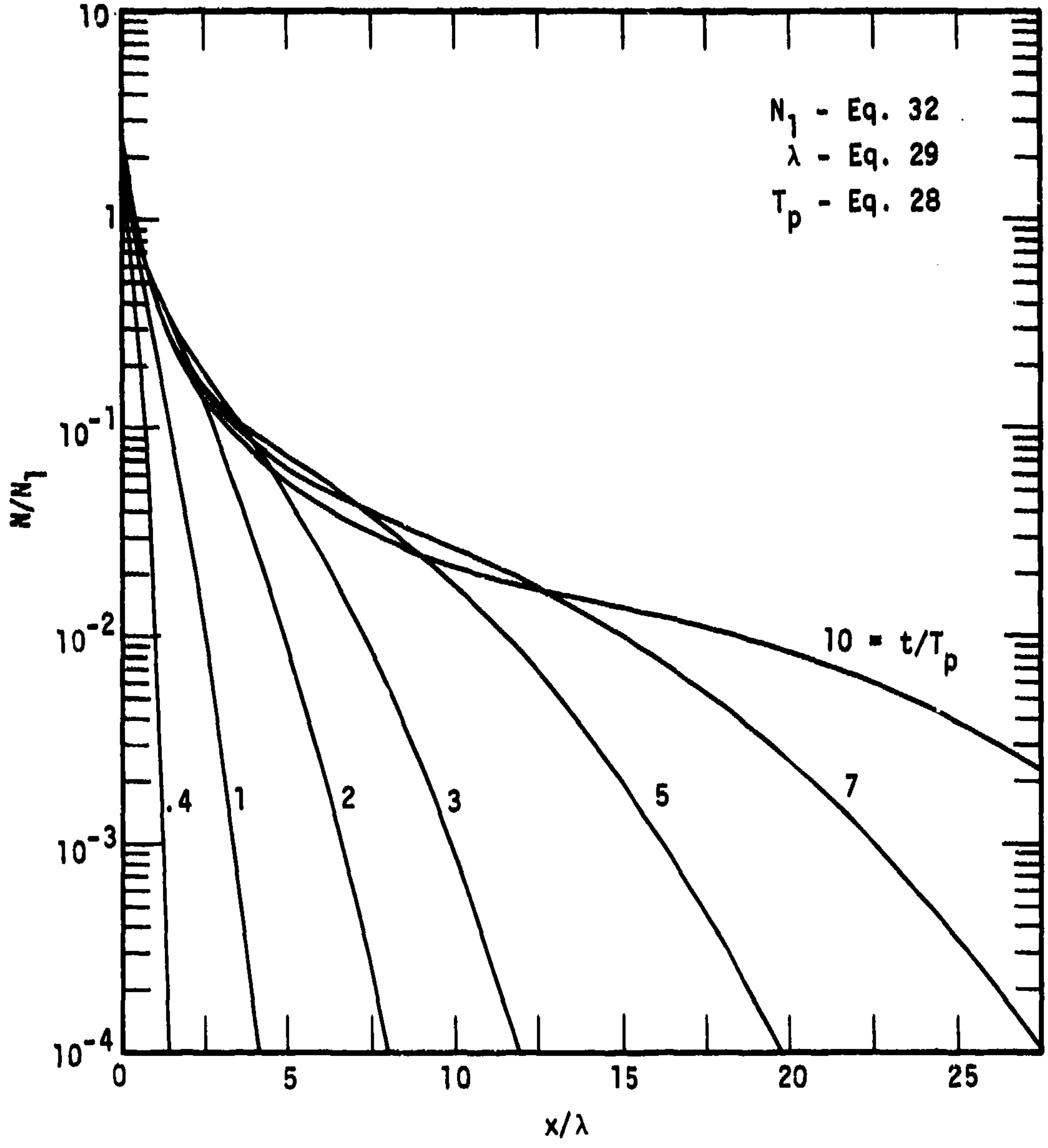



Figure 26. Number density vs. x at various times.

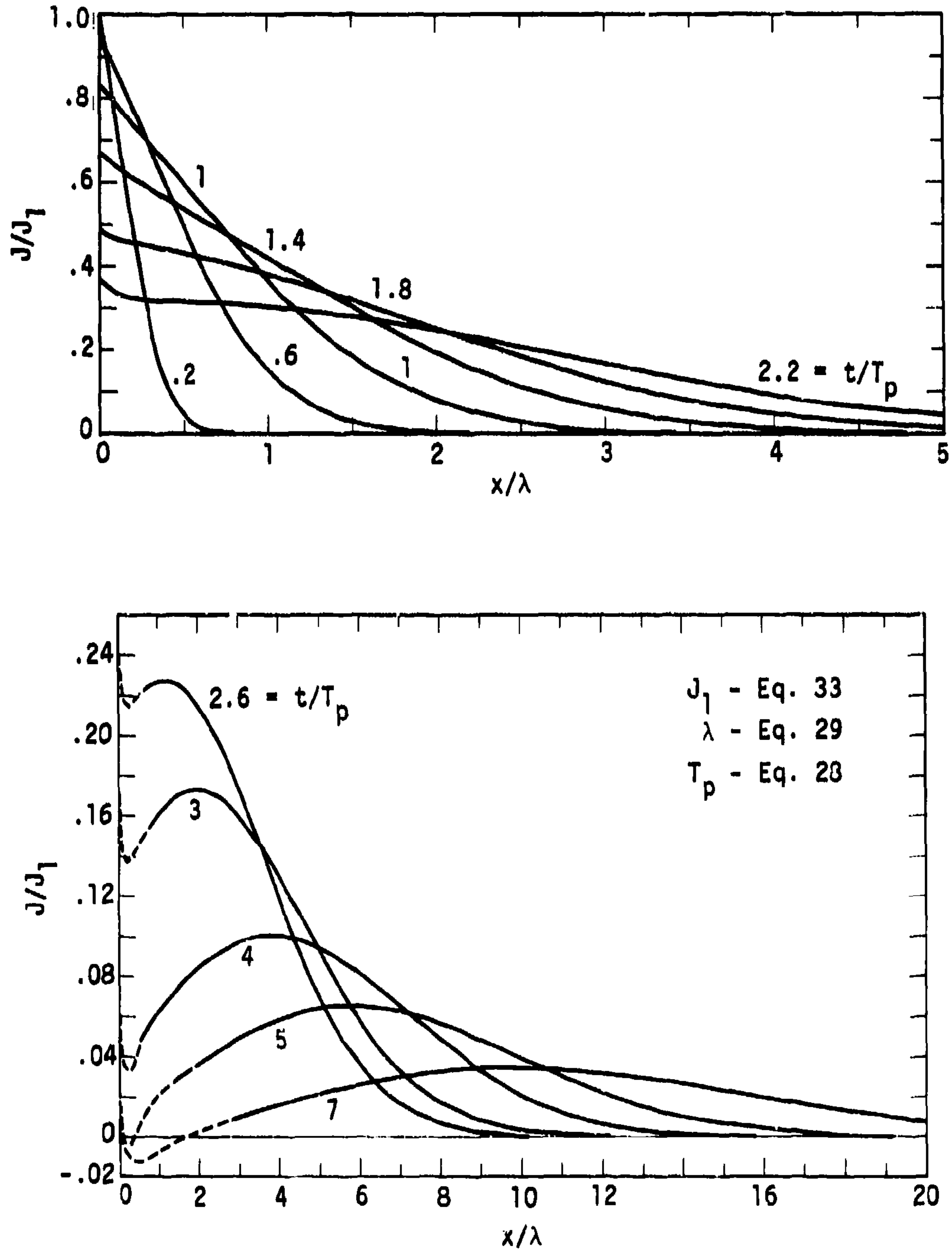



Figure 27. Current density vs. x at various times.

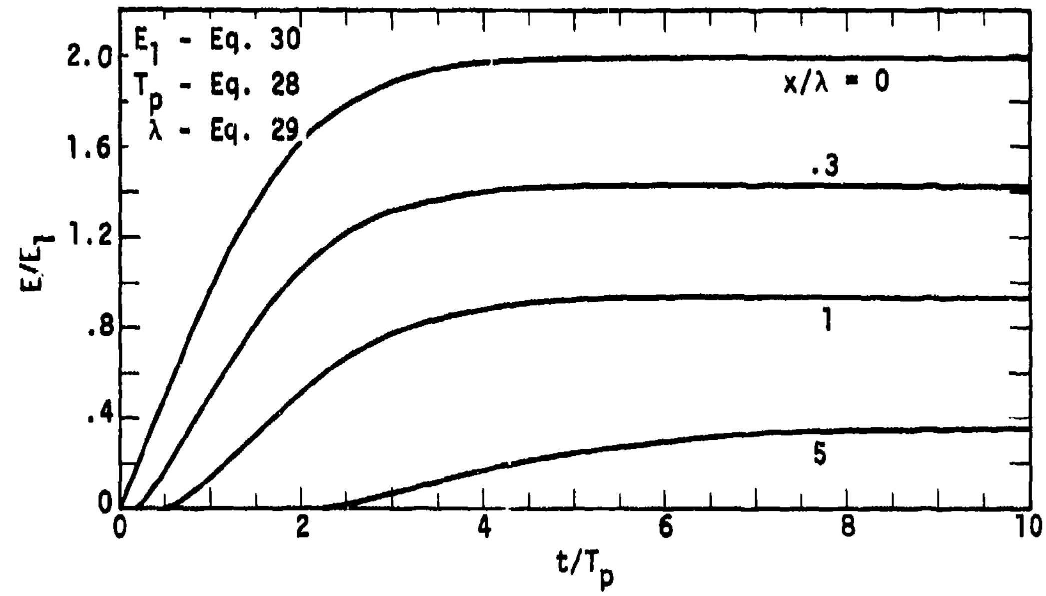



Figure 28. Electric field vs. time at various x.

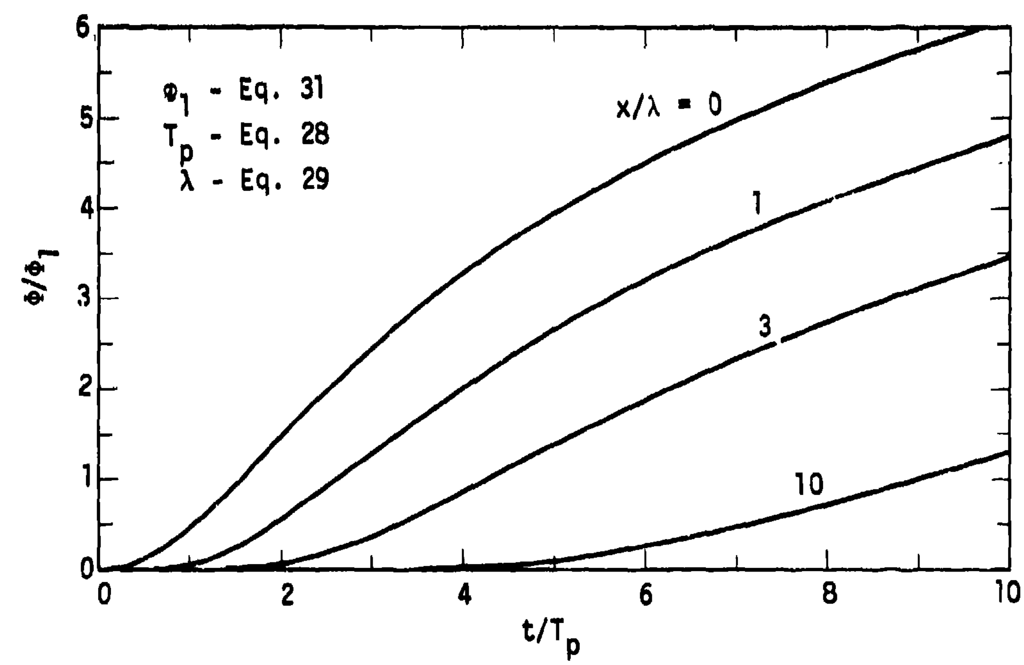



Figure 29. Potential vs. time at various x.

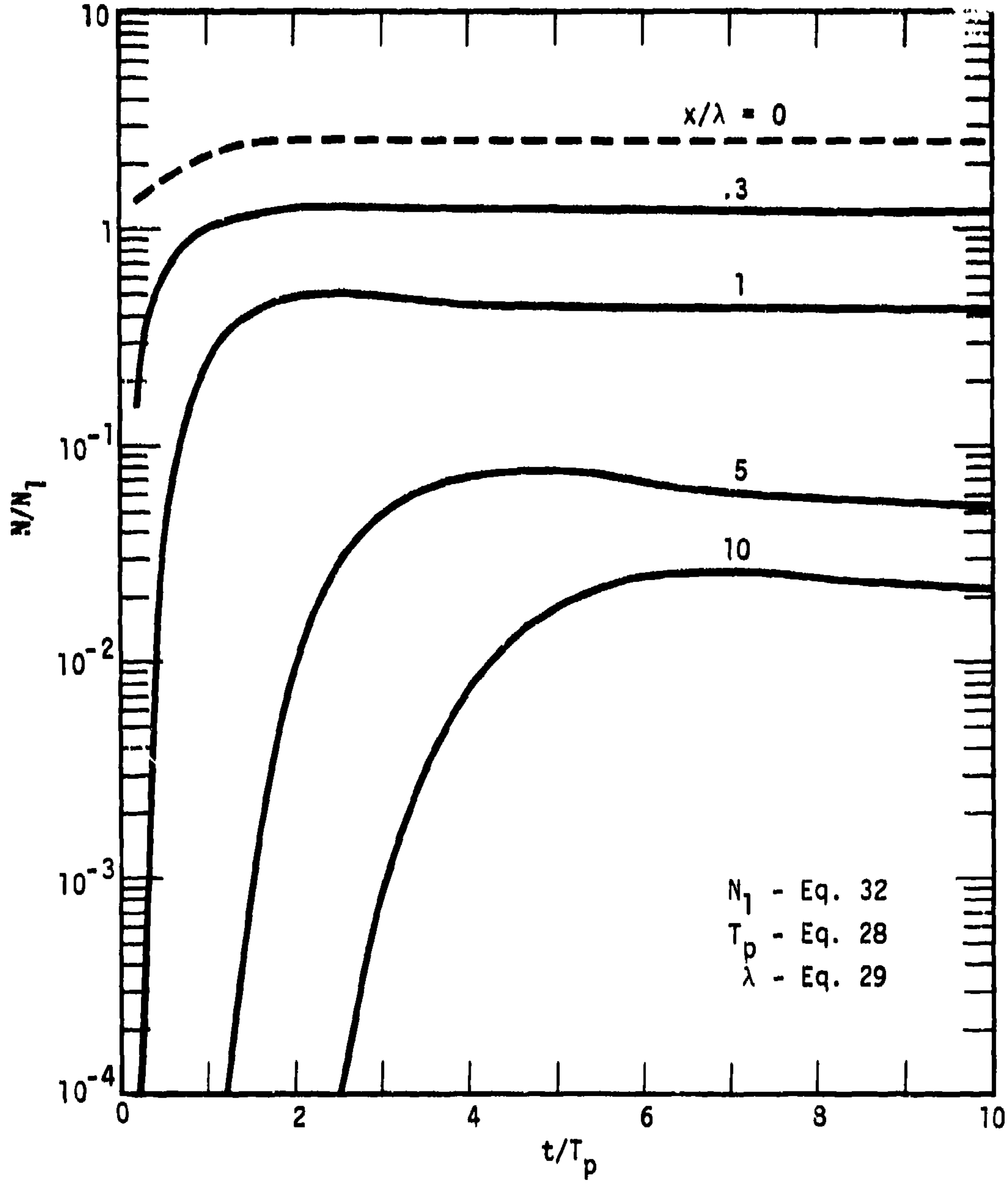



Figure 30. Number density vs. time at various x.

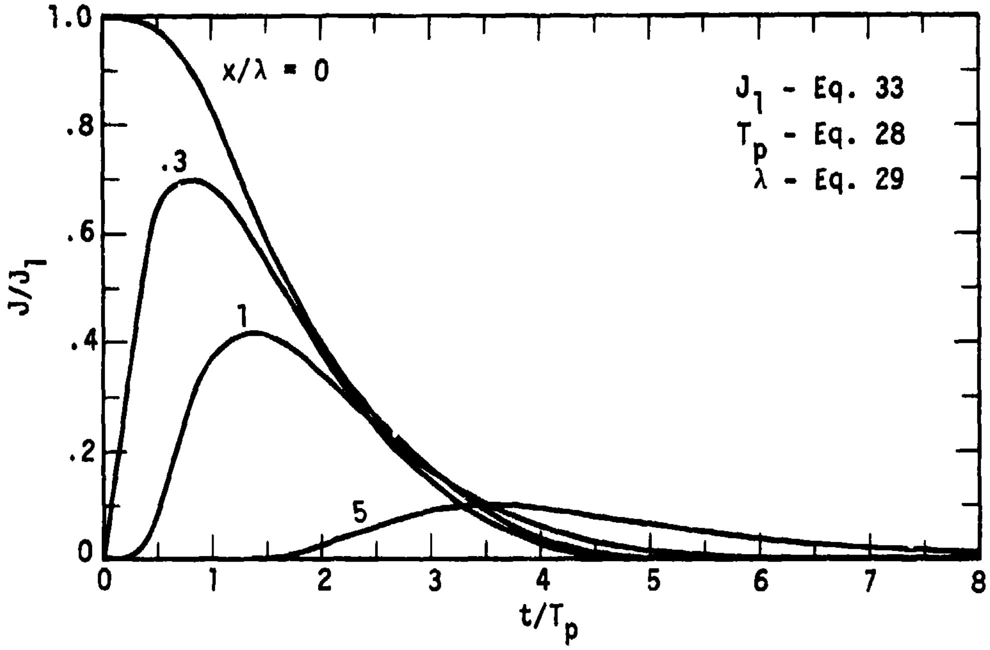



Figure 31. Current density vs. time at various x.

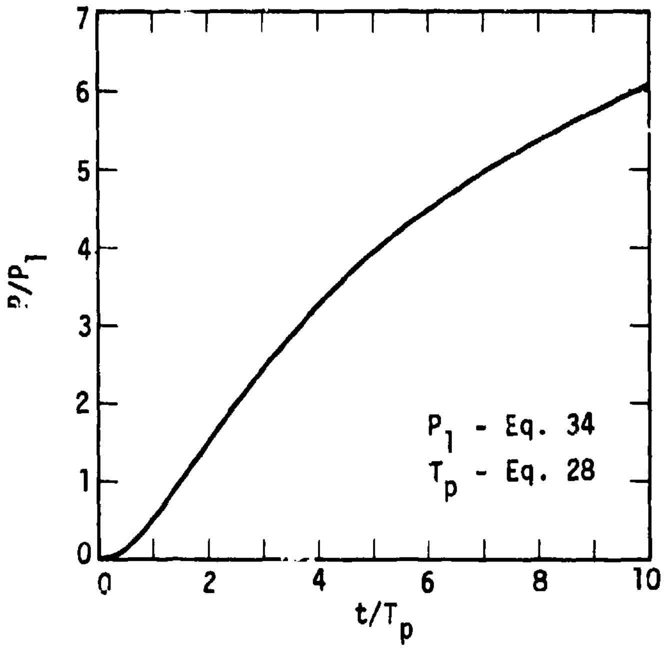



Figure 32. Dipole moment per unit area vs. time.

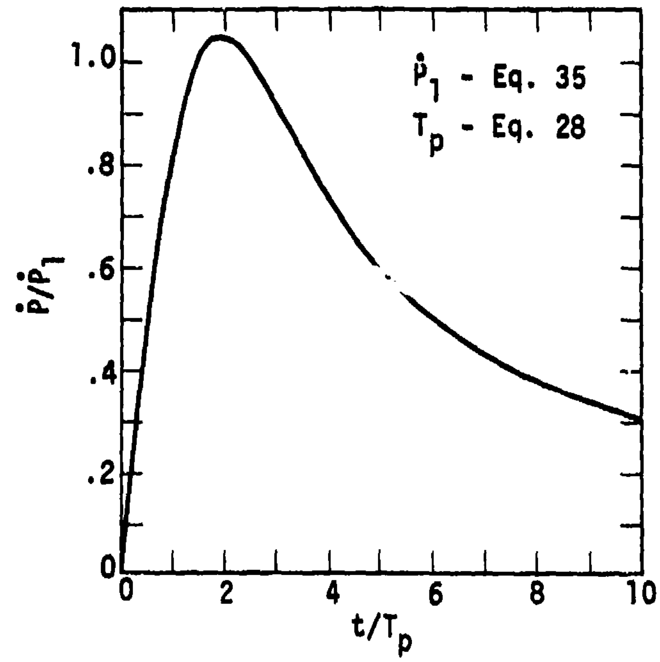



Figure 33. Time derivative of dipole moment vs. time.

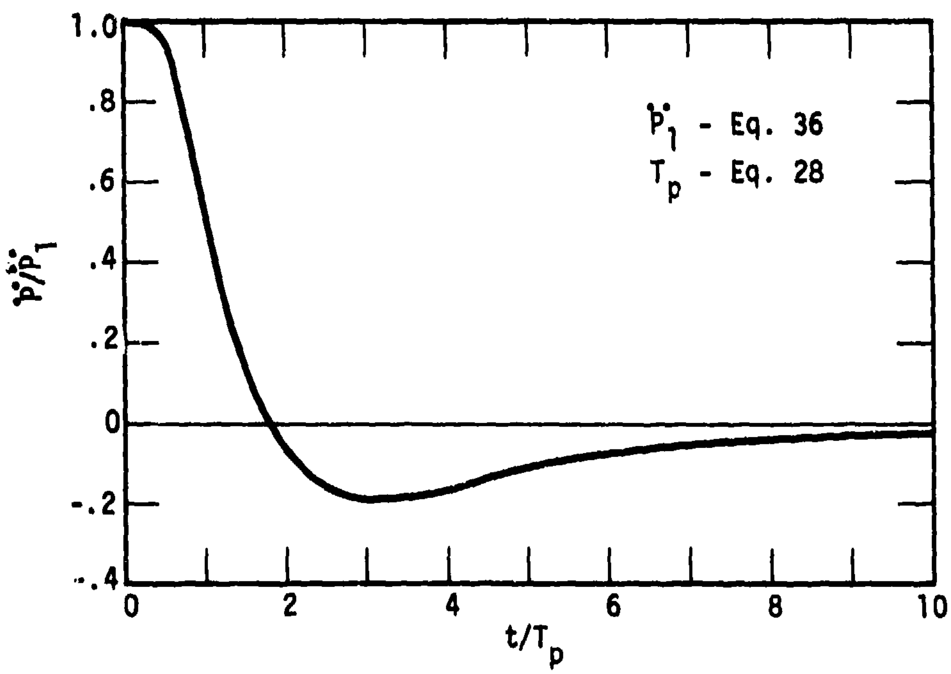



Figure 34. Second time derivative of dipole moment vs. time.

## SECTION 6
## CONSTANT PULSE, LINEAR-TIMES-EXPONENTIAL ENERGY SPECTRUM

Here we present results for the constant pulse $(p=0)$ and linear-times-exponential energy spectrum, Equation (8). $\overline{E}$, Y, and $R_o$ are in the same units as the previous section (keV, $cal^{-1}$, $cal/cm^2/sec$).

Equations (5) and (9) show the time unit is

$$T_p = \left[\frac{m\,\overline{v}}{4\pi e^2\, Y\, R_o}\right]^{1/2}$$

$$= 0.7227 \left[\frac{\sqrt{\overline{E}}}{Y\,R_o}\right]^{1/2} \quad \text{sec} \quad , \qquad (37)$$

and the unit of length is

$$\lambda = \overline{v}\, T_p = 1.201 \times 10^9 \left[\frac{\overline{E}^{3/2}}{Y\,R_o}\right]^{1/2} \quad \text{cm} \quad . \qquad (38)$$

The units of electric field $(E_1)$ and potential $(\Phi_1)$ are

$$E_1 = \frac{m\,\overline{v}}{e\,T_p} = 1.308 \times 10^{-4}\left[\sqrt{\overline{E}}\; Y\; R_o\right]^{1/2} \quad \text{V/m} \quad , \qquad (39)$$

$$\Phi_1 = \lambda\, E_1 = \frac{\pi}{2}\frac{\overline{E}}{e}$$

$$= 1.571 \times 10^3\, \overline{E} \quad \text{Volts} \quad . \qquad (40)$$

The units of number density $(N_1)$ and current density $(J_1)$ are

$$N_1 = \frac{Y\ R_o}{\overline{v}} = 6.016 \times 10^{-10} \frac{Y\ R_o}{\sqrt{\overline{E}}} \quad cm^{-3} \quad , \tag{41}$$

$$J_1 = e\ N_1\ \overline{v} = 1.602 \times 10^{-15}\ Y\ R_o \quad Amps/m^2 \quad . \tag{42}$$

The units of dipole moment per unit area $(P_1)$ and its time derivative $(\dot{P}_1)$ are

$$P_1 = e\ \lambda^2\ N_1 = \frac{\overline{E}}{8e}$$

$$= 1.391 \times 10^{-8}\ \overline{E} \quad Coul/m \quad , \tag{43}$$

$$\dot{P}_1 = \frac{P_1}{T_p} = 1.924 \times 10^{-8} \left[\overline{E}^{3/2}\ Y\ R_o\right]^{1/2} \quad Amps/m \quad . \tag{44}$$

Finally, the unit of the second time derivative of the dipole moment per unit area is

$$\ddot{P}_1 = \frac{\dot{P}_1}{T_p} = 2.663 \times 10^{-8} \sqrt{\overline{E}}\ Y\ R_o \quad Amps/m/sec \quad . \tag{45}$$

Figures 35 through 45 give the dynamical solutions for the case of a constant X-ray pulse starting at $t=0$ and a linear-times-exponential energy spectrum. The units are those of Equations (37) through (45).

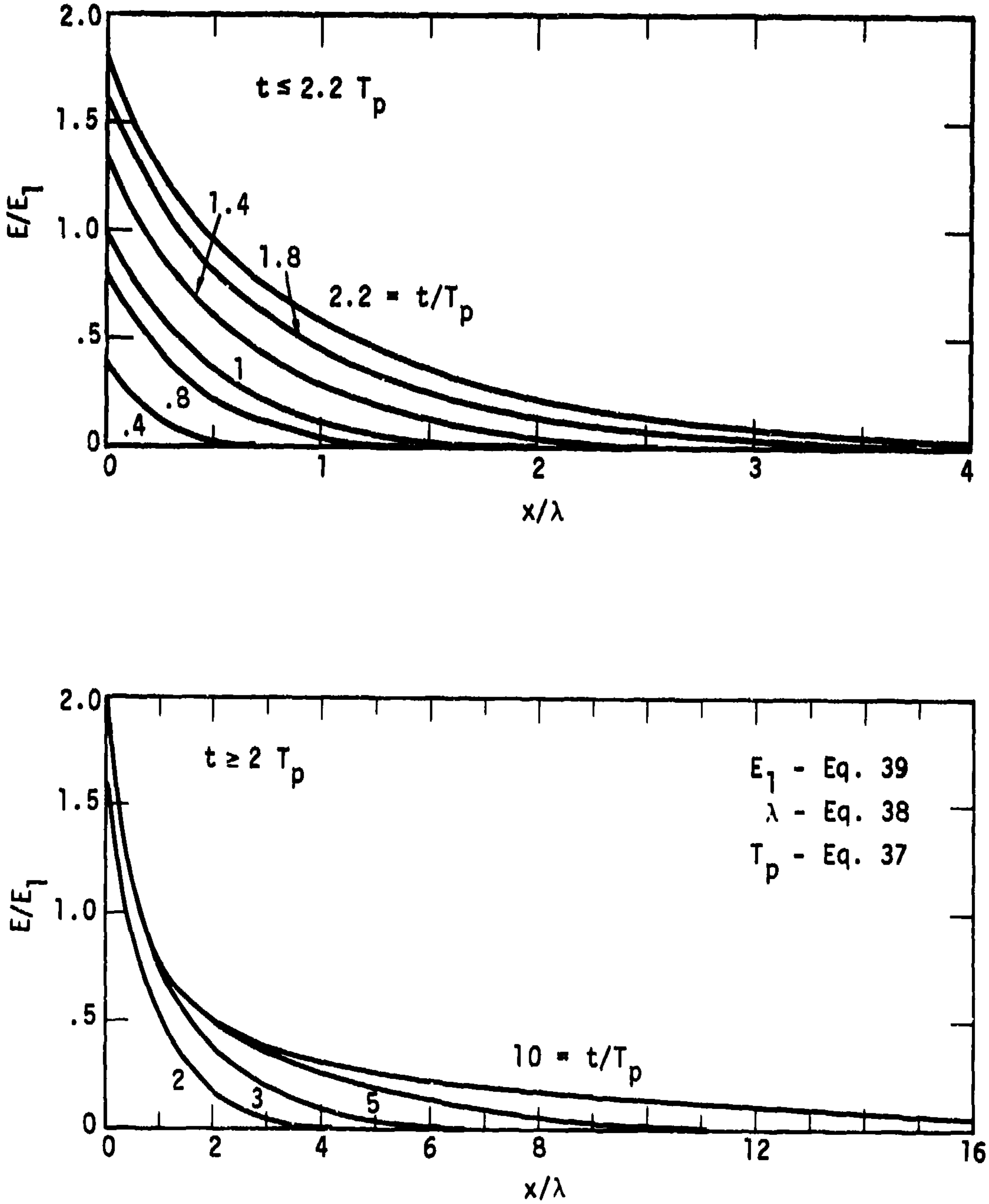



Figure 35. Electric field vs. x at various times.

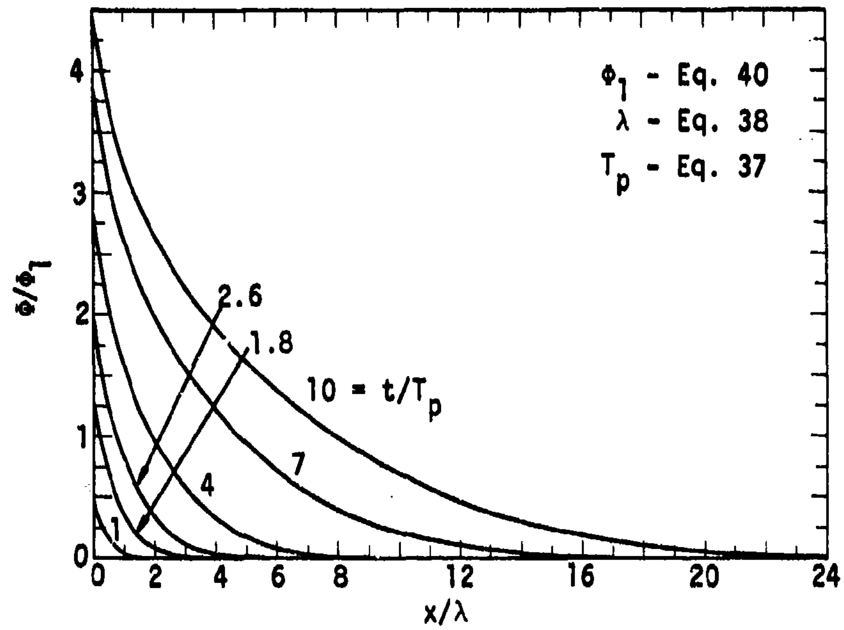



Figure 36. Potential vs. x at various times.

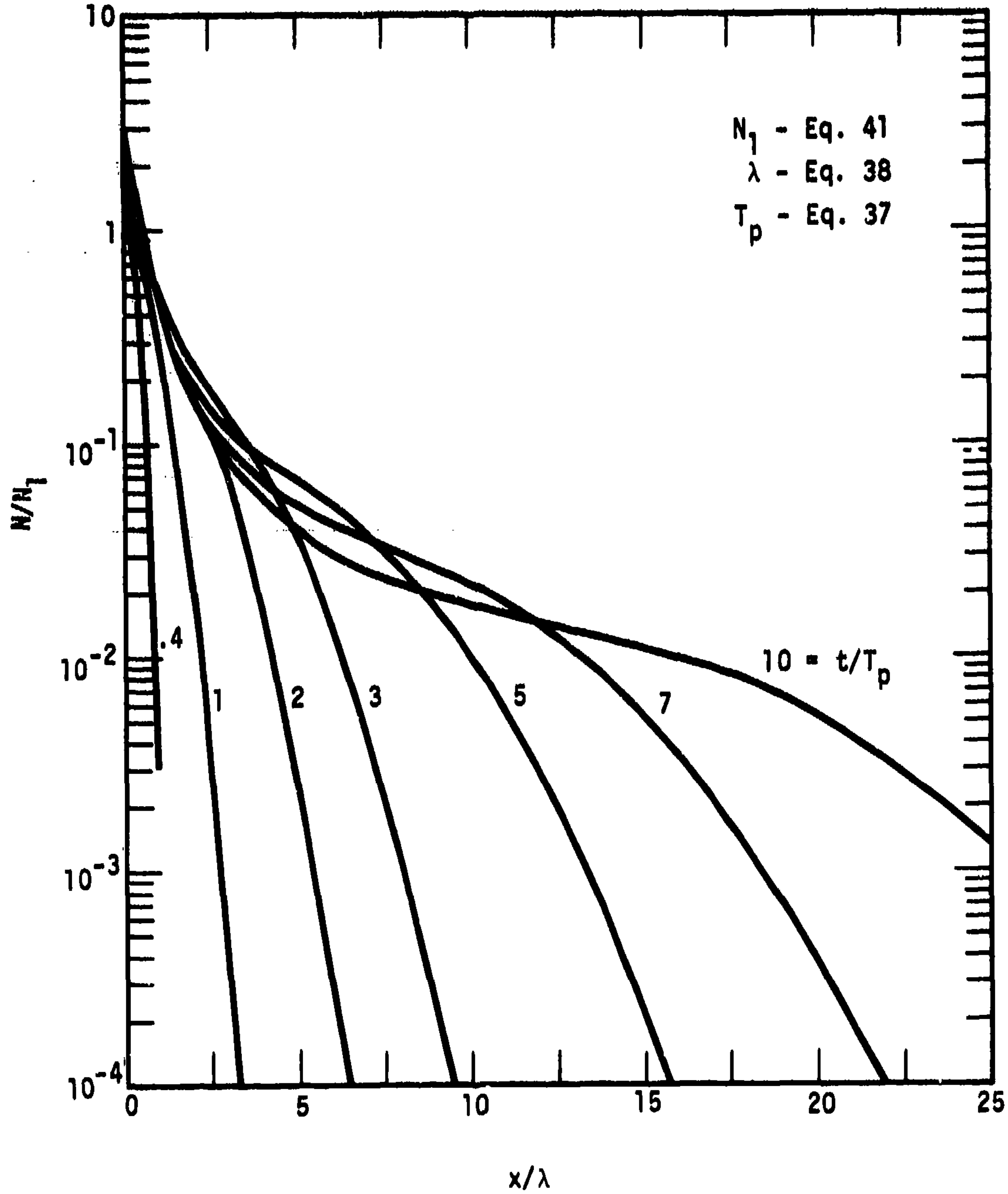



Figure 37. Number density vs. x at various times.

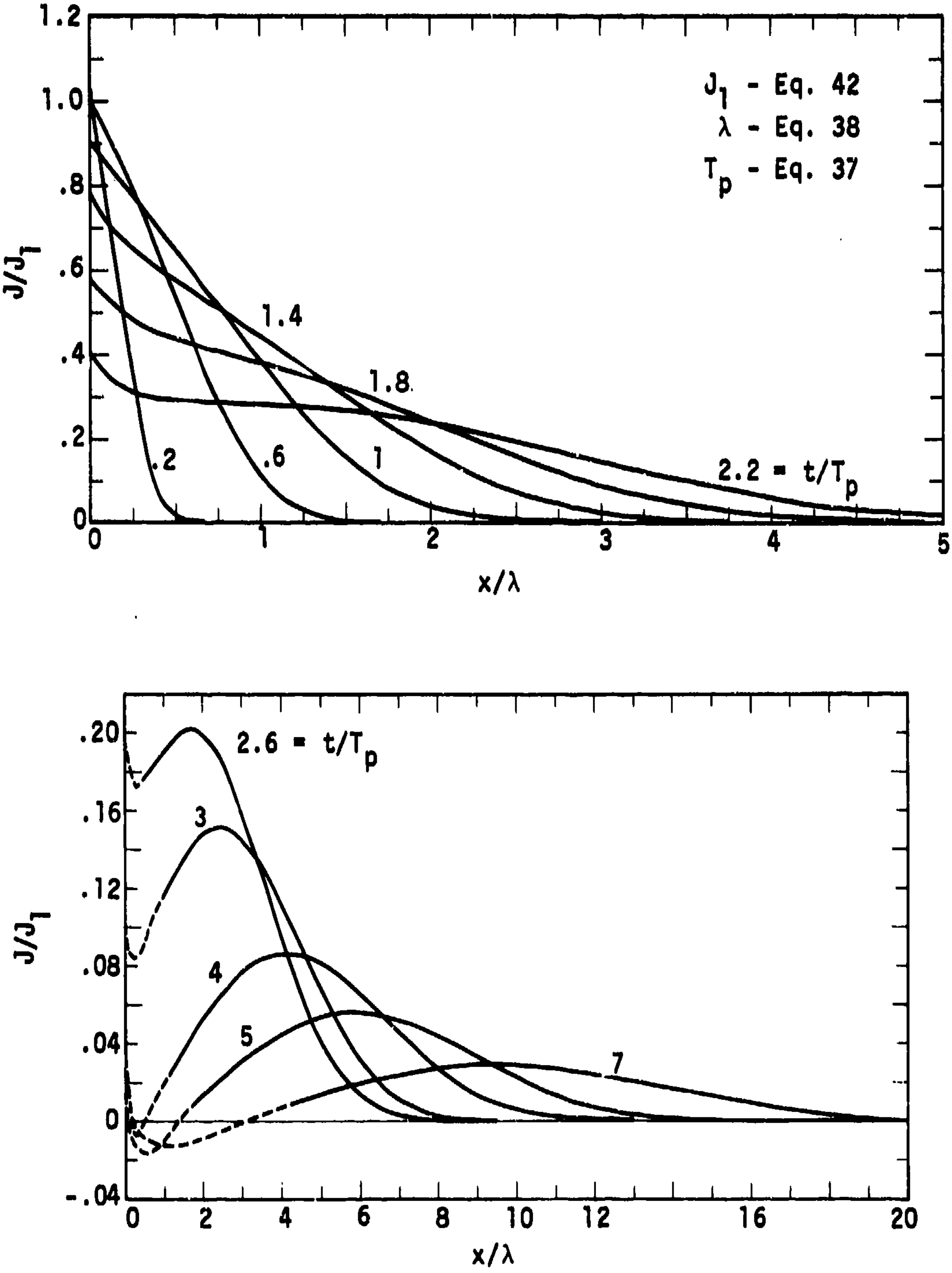



Figure 38. Current density vs. x at various times.

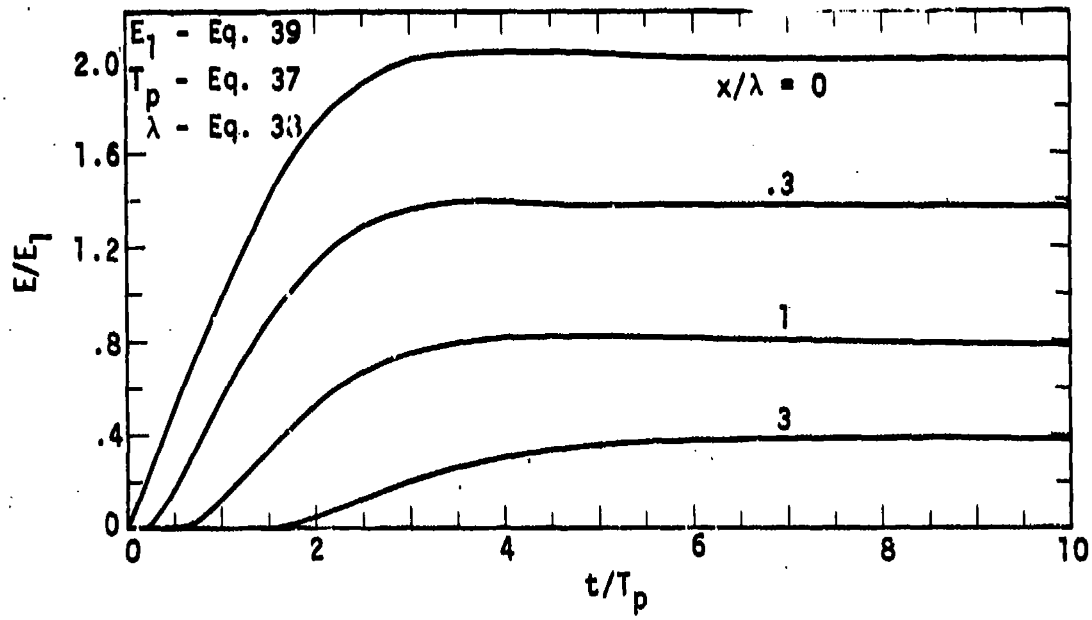



Figure 39. Electric field vs. time at various x.

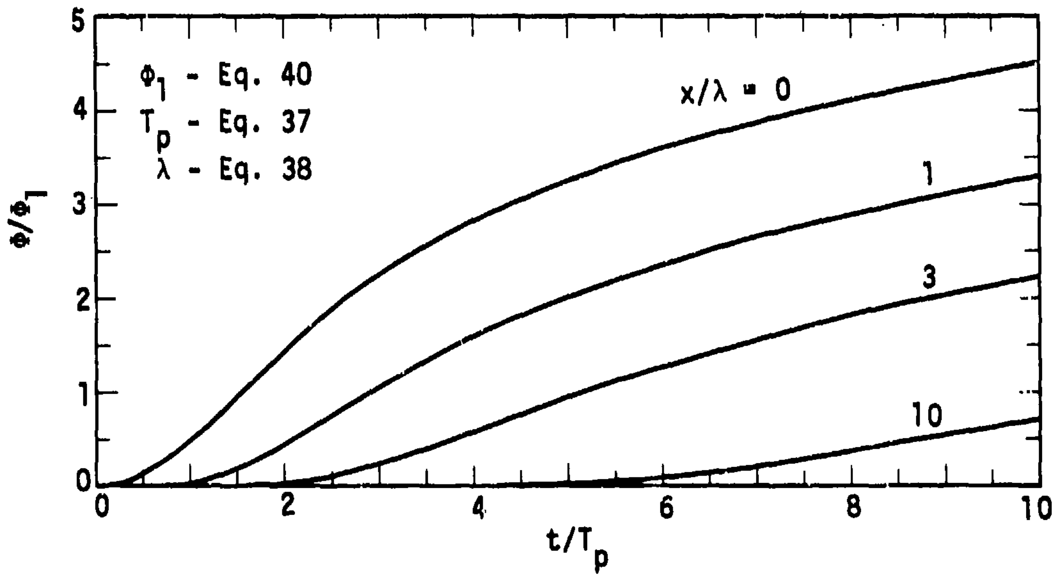



Figure 40. Potential vs. time at various x.

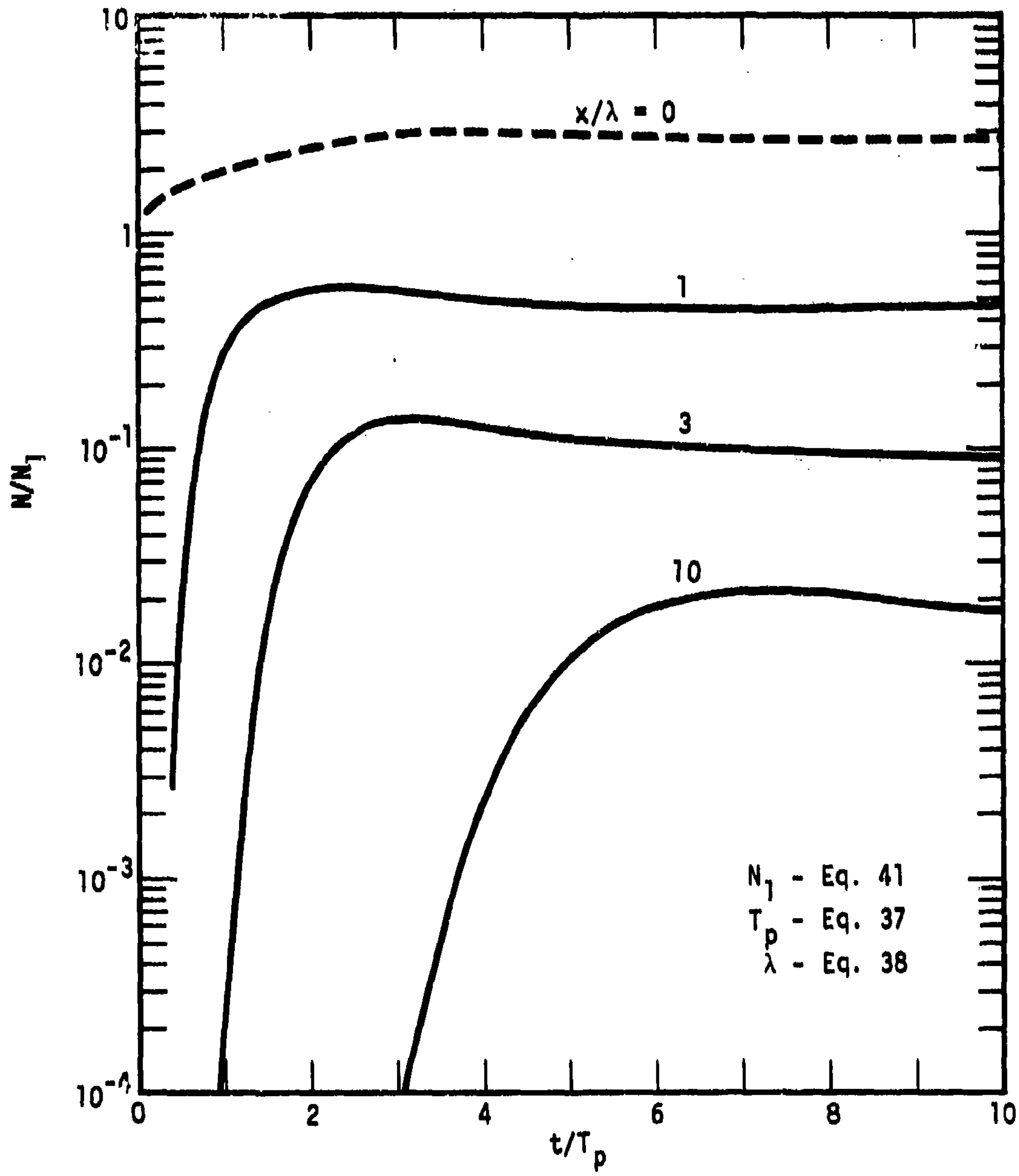



Figure 41. Number density vs. time at various x.

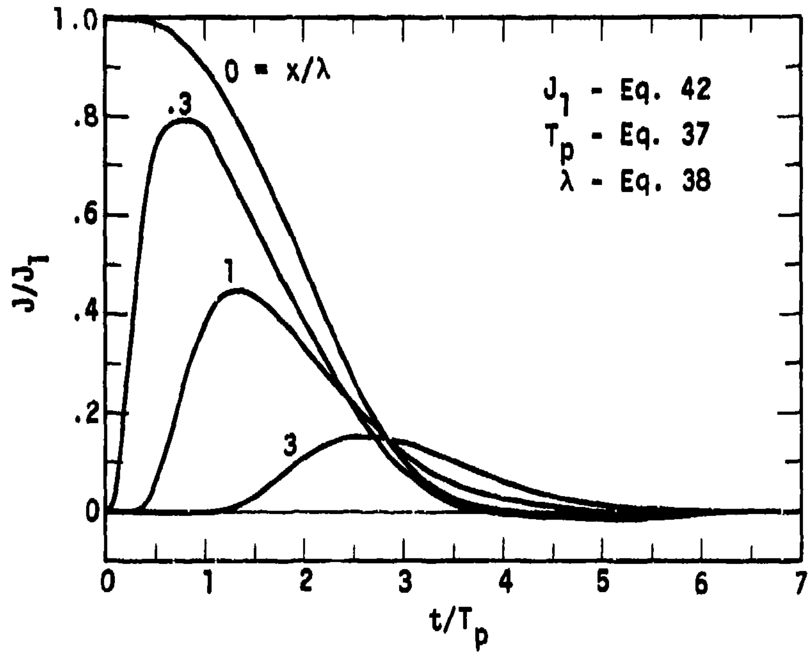



Figure 42. Current density vs. time at various x.

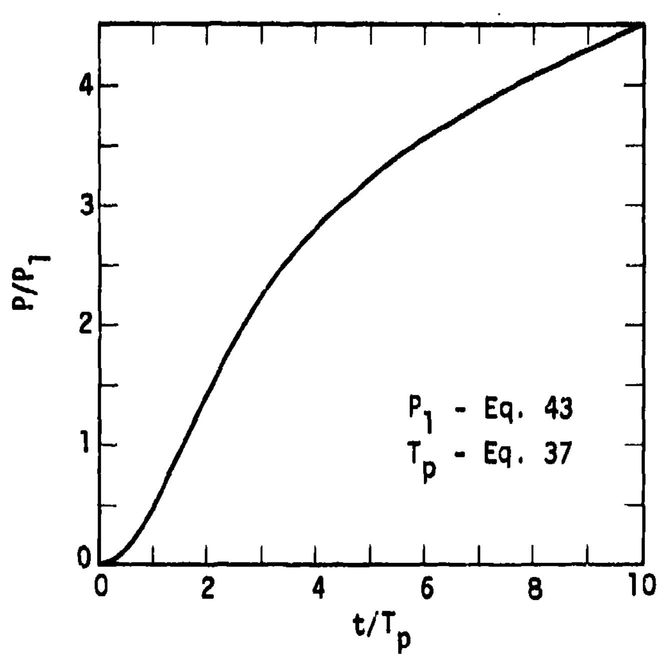



Figure 43. Dipole moment per unit area vs. time.

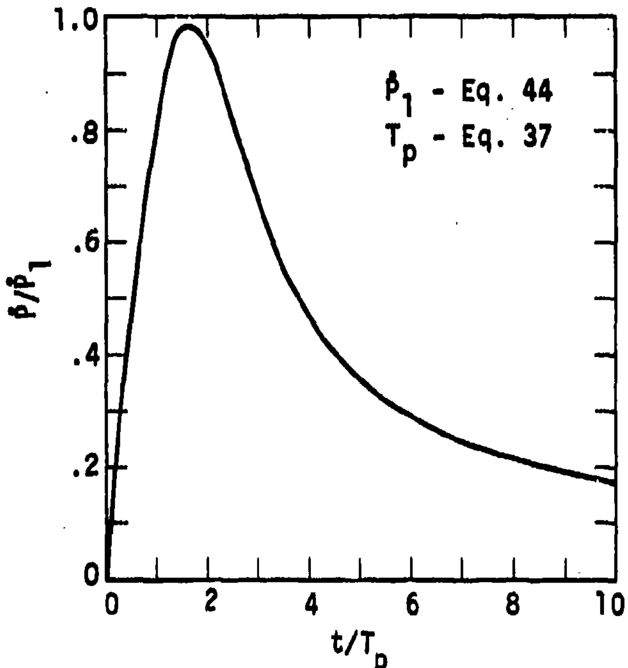



Figure 44. Time derivative of dipole moment vs. time.

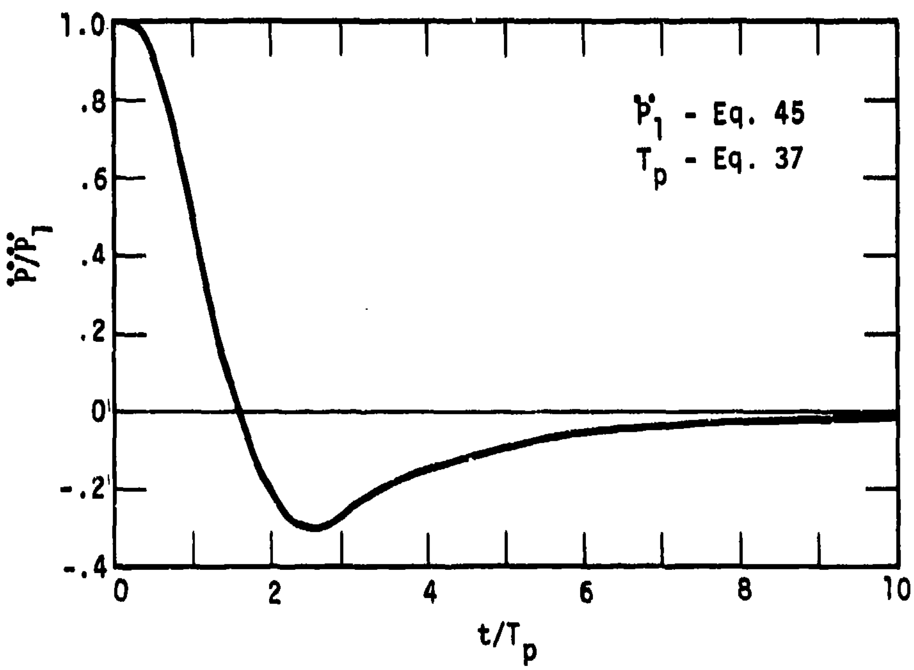



Figure 45. Second time derivative of dipole moment vs. time.

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